NPS ARCHIVE
1966
CIBOCI, J.

VERIFICATION OF MAZEIKA'S METHOD OF THERMOCLINE DEPTH PREDICTION FOR THE NORTHEAST PACIFIC OCEAN

JOHN WILLIAM CIBOCI

LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIF. 93940

DUDLEY KNOX LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY CA 93943-5101

This document has been approved for public
release and sale; its distribution is unlimited.

12

VERIFICATION OF MAZEIKA'S METHOD

OF THERMOCLINE DEPTH PREDICTION

FOR THE NORTHEAST

PACIFIC OCEAN

by

John William Ciboci
Lieutenant, United States Navy
B. S., University of Idaho, 1959

Submitted in partial fulfillment
for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

UNITED STATES NAVAL POSTGRADUATE SCHOOL
October 1966

NPS Archive
1966
Ciboci, J.

Th[illegible]
C[illegible]22

ABSTRACT

Mazeika's method for forecasting mixed-layer (thermocline) depth of the upper ocean layers is discussed along with a newer version of this method developed by James. Using Mazeika's method primarily, a verification for the Northeast Pacific Ocean was completed with data from Ocean Weather Stations PAPA (50N, 145W) and NOVEMBER (30N, 140W) and a point named MIDPOINT (40N, 140W). The results indicate Mazeika's method is successful at Station PAPA more than seventy-five percent of the time during the heating season followed by a rapid decline as the cooling season begins. The method should be useful in the entire Central Subarctic Domain as described by John P. Tully. The method fails at NOVEMBER and MIDPOINT producing less than thirty percent success in prediction. James' version did not improve the results obtained at Station NOVEMBER. This failure appears to be due to the controlling parameters for processes in the Subtropic or Transitional oceanographic regions (which include NOVEMBER and MIDPOINT); these differ from parameters controlling oceanic processes in the Pacific Subarctic region (Station PAPA), which resemble those involved in the Atlantic region for which Mazeika's method was developed.

Climatology data which can be used to obtain surface and 400-foot level temperature are also tested. The results indicate these data are very useful and accurate in determining the stability index required of Mazeika's method.

L...
NAVAL POSTGRADUATE ...
MONTEREY, CALIF. 9...

TABLE OF CONTENTS

[illegible]

1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]
5. [illegible]
6. [illegible]
7. [illegible]
8. [illegible]
9. [illegible]
10. [illegible]
11. [illegible]

[illegible]

[illegible]

LIST OF ILLUSTRATIONS

List of Illustrations (Cont'd)

LIST OF TABLES

1. Background.

The United States Navy is expending much effort in the direction of anti-submarine warfare. The proper use of anti-submarine detection devices hinges on the capability of correctly predicting the thermocline depth in the various oceans. Any reliable method which can be easily and properly used by the men and equipment of the anti-submarine forces would add to the overall defense capability of our country. To this end, the testing of one particular method of thermocline depth prediction was undertaken.

2. Introduction.

Mazeika's method utilizes a subjective but realistic approach to the thermocline depth prediction problem. The thermocline depth predicted by this procedure is the mean depth of the interface between the mixed layer and the thermocline. The method requires the use of easily obtainable inputs such as forecast wind speed, fetch, wind duration and the synoptic weather picture. Subjective aspects of this method come to light in certain choices which are made by the user of the prediction technique, as will be explained later.

Various types of vertical mixing are included in Mazeika's method. They are mechanical mixing, which is due to the combined effect of wind waves and associated wind currents; instability mixing due to advection and density changes; and mixing due to vertical convergence-divergence caused by changes in the overlying atmospheric pressure field, or by convergence-divergence in the surface current field. Mechanical mixing is introduced into the method by use of a sea state parameter which is based on the wind wave characteristics of the area under investigation. The use of a stability index and corrections for the salinity gradient were chosen to satisfy the requirements of instability mixing. Finally, convergence-divergence is accounted for in the construction of graphs used to determine the mixed-layer depth.

Mazeika combined the use of these mixing parameters with the study of BT data, weather charts and simultaneous weather and wave observations from the Atlantic Ocean Weather Station (OWS) CHARLIE (52N, 35W) to develop his prediction procedure empirically. After development was completed, data from Atlantic OWS BRAVO (56.5N, 51W), ECHO (35N, 48W),

and DELTA (44N, 41W) were used to test the method. No data from the Pacific ocean weather stations were used for the empirical development of the method or for its testing.

Mazeika has stated that his prediction method can generally be used anywhere in the ocean without previous information on the mixed layer and thermocline; the only requirement is knowledge of the surface wind waves and the stability index. The testing of Mazeika's method in the Pacific Ocean would serve to substantiate this claim by Mazeika or possibly bring to light weaknesses in the method which may be present.

3. Mazeika's Method.

Mazeika (1960) considered the mixed-layer thickness, h, to be a function of wave amplitude A, wavelength λ, and a mixing parameter k, which is valid at the interface between the mixed layer and the thermocline. The mixing parameter cannot be expected to remain constant. Since it applies to the bottom of the mixed layer, it must be dependent on mixed-layer thickness and on the wave parameters. In addition, its value depends on the stability in the thermocline.

The relation describing orbital motion in trochoid waves

$$k = A e^{-\frac{2\pi h}{\lambda}} \tag{1}$$

includes most of the parameters, if h is considered to be a fixed value under given surface conditions and if stability in the thermocline is constant. The above function, $k(A, h, \lambda)$, was adopted by Mazeika in view of the generally accepted theory that orbital motion of particles due to waves decreases exponentially with depth and is proportional to the wave parameters.

Solving (1) for h,

$$h = \frac{\lambda}{2\pi} \ln \left(\frac{A}{k}\right). \tag{2}$$

Equation (2) can be used to compute h, if the wave parameters and the corresponding value of k for existing stability in the thermocline are known.

In the above equations the amplitude (A) is one-half of the significant wave height ($H_{1/3}$); wave length (λ) was computed by the relation $\lambda = 3.41T_{max}^2$, where T_{max} is the period of maximum energy of the spectrum for a fully-developed sea.

On the assumption that vertical temperature difference is proportional to the mean temperature gradient in the upper part of the thermocline, Mazeika adopted the difference in the entire thermocline as the index of stability (a salinity correction could be added, see Table I). Since most BT data usually reach a depth of 400 feet, Mazeika selected the difference between the surface and the 400 foot level as the stability index

$$\overline{\Delta T} = T_o - T_{400}.$$

A deeper layer (e.g., 600 feet) could be taken if data were available.

A certain initial stability exists with a given $\overline{\Delta T}$ in the absence of a mixed layer. If the mean stability index remains constant, stability increases from the initial value with increasing mixed-layer thickness. Increase of stability is slow when the mixed layer begins to form and gradually becomes greater as the mixed-layer thickness and ΔT increase.

To connect mixing parameter values with stability and wave parameters, another parameter (sea state parameter) was introduced by Mazeika

$$\eta = H_{1/3}T_{max}$$

η is used as a measure of sea state for wind waves. k values determined from equation(1)with known wave parameters and mean mixed-layer thickness $(\overline{h})$ values were plotted against η values computed with corresponding wave parameters for eight groups of $\overline{\Delta T}$. Curves which fit the distribution of points for each $\overline{\Delta T}$ group were computed and resulted in the solid-line curves of figures 1-8. $\overline{h}$ values which were related

to the $k(\eta)$ curves were then computed and plotted as the dashed-line curves on figures 1-8. The central $\bar{h}$ curve applies to normal mixing, the upper $\bar{h}$ curve applies to convergent situations with horizontal convergence occurring in the upper ocean layers adjacent to the point of interest, while the lower $\bar{h}$ curve applies to situations with horizontal divergence. A later discussion covers procedures used in determining which $\bar{h}$ curves apply for a particular location. The $\bar{h}$ curve is used to determine the mixed-layer thickness in feet from the $\bar{h}$ scale on the left margin of figures 1-8.

Richard W. James (1966) of the Naval Oceanographic Office has developed a new version of thermocline depth prediction based entirely on Mazeika's method. This author had completed most of the Pacific verification data before James' version was published so that only limited testing of it was introduced in this report.

James believes Mazeika's model to be the most realistic approach to wind mixing to date, but points out that no account is taken of the demonstrated time lag between onset of wind and the mixing subsequently generated, and also that it is overly sensitive to low wave conditions. James has corrected these deficiencies in new figures which are described below, and has redefined the stability index to what he believes is a more realistic parameter.

James retained the sea state parameter, η, as defined by Mazeika, but he replaced its determination method by developing a new graph (figure 9) which is based on wave forecasting procedures of Pierson, Neumann, and James (1955). This can be used in all cases of fully- or non-fully-developed sea.

To account for the time lag between occurrence of wind and subsequent mixing James developed Table II. This table gives approximate time periods for a given η value to stabilize, since a certain wind requires a given time to develop a maximum η value. If this time requirement is not met then a lower η value must be considered.

James also believed that Mazeika's stability index, $\overline{\Delta T}$, is a fairly conservative factor and that it may not be representative of the resistance to mixing in many cases. Thus, he redefined the stability index (ΔT_1) as the temperature gradient, in °F/100 feet, at the most shallow thermocline. The thermal gradient does not have to extend through 100 feet since only the rate of change is desired.

Salinity corrections for this method are obtained from figure 10. The correction is given in °F/100 feet and is added to the previously determined stability index (ΔT_1). The amount of correction is proportional to the salinity gradient, water temperature, and the mixing factors.

James also developed new mixed-layer depth forecasting curves from the formula:

$$LD = \frac{K_1}{\Delta T_1}(1 - e)^{-K_2 \Delta T_1 \eta}$$

where K_1 and K_2 are constants. These new curves are depicted in figure 11. Convergence and divergence was accounted for in this figure by using the next ΔT_1 curve above the normal ΔT_1 curve for convergence, and the ΔT_1 curve below the proper value for divergence.

The effects of swell on the mixing of water was also considered by James, who states that a much reduced value of η should be used for swell. The reduction of the mixing force with swell is due to the

narrowness of the period band, lack of breaking crests, and reduced angular spreading. He also states that swell caused from decaying wind waves in a fetch still possesses some of the characteristics of sea and should represent about 50 percent of η while swell arriving from a distant storm would represent approximately 25 percent of η. This reduction is strictly a subjective estimate.

4. Mazeika's Prediction Procedure.

To use the method properly, the stability index must be determined first and corrected for salinity gradient if possible. This determination can be accomplished in various ways based on:

(1) averaging temperature differences between the surface and the 400-foot level for four to six bathythermograph (BT) observations taken within the time interval of 24 hours, preferably; the time interval could be longer, however, up to a maximum of ten days.

(2) climatology data records (monthly or seasonal) which give sea surface temperature and the temperature at 400 feet. (The accuracy of these data will be discussed later.)

(3) synoptic sea surface chart and climatological data for 400 feet.

After $\overline{\Delta T}$ has been determined, the salinity gradient correction can be applied if such data are available. The salinity correction is found by entering Table I with the mean temperature in the mixed layer and the salinity difference ($^{o}/oo$) in the mixed layer and coming out with a value $\overline{\Delta T}'$. This value is then used to determine the correction $C = -\overline{\Delta T}'-1°$ for negative salinity gradients or $C = \overline{\Delta T}'-1°$ for positive salinity gradients, since $k(\eta)$ curves actually correspond to 1°F higher stability indexes. This C correction is then applied to the original $\overline{\Delta T}$ value to determine the proper graph for the mixed layer prediction.

The next step in the prediction procedure is to determine the sea state parameter η. This can be done by the use of Table III which lists values of wave parameters and minimum fetch and duration for various

windspeeds for a fully-developed sea. For application in a non-fully-developed sea, $H_{1/3}$ and T_{max} are taken from graphs in H.O. 603 and is then computed with the equation $\eta = H_{1/3}T_{max}$.

The forecast windspeed can be a critical factor in determining an accurate η. The error in mixed-layer depth prediction caused by erroneous windspeed is greater with a small stability index than with a larger one. To illustrate, an error of 1 knot in windspeed could produce a difference of 16 feet in the predicted mixed-layer depth using a stability index of 2° while this same error would produce a difference of 6 feet using a stability index of 13°. The accurate forecast of windspeed is imperative to an accurate mixed-layer prediction.

Finally, a decision must be made as to whether an area is undergoing horizontal divergence or convergence which may influence the effectiveness of the mixing processes. This is a difficult problem which is approached subjectively through a study of the forecast area. Some areas may be under the influence of permanent convergent or divergent systems which may preclude conventional mixing processes. To aid in this determination Mazeika has illustrated in figures 12 and 13 what he believes to be areas of strong convergence and divergence. Figures 12 and 13 were used as guide lines by this author in the verification procedure and they seemed to work quite well. Laevastu and Hubert (1965) note that convergence and divergence usually depend on a subjective estimation and they recommend the alternative of calculation of divergence and convergence from surface current fields.

After the required parameters have been determined and the appropriate graph selected the thermocline depth can be determined. The η value is found on the far left margin of the graph (figures 1-8).

From the horizontal intersection of this value with the proper $k(\Gamma)$ solid-line curve (normal, convergent or divergent), proceed vertically to intersect the corresponding dashed curve, $\bar{h}(k)$. Then proceed horizontally to the $\bar{h}$ scale on the left margin to determine the thermocline depth.

5. Verification Procedure.

The requirements for the use of Mazeika's method are explicit. To meet these requirements a search for data was initiated and led immediately to the elimination of all data which included only one BT per day. These sources were mainly commercial and military ship reports. Since data from Ocean Weather Stations PAPA (50N, 145W) and NOVEMBER (30N, 140W) were readily available at the Naval Postgraduate School, a decision was made to limit the verification to the Northeast Pacific Ocean. Also, the difference in geographical location of these two stations in the Northeast Pacific Ocean area would serve to test the procedure in perhaps different ocean regions within this broad area.

Data for Station PAPA were taken from booklets prepared by the Canadian Oceanographic Data Center. This source is considered excellent as all parameters were included in it except the synoptic weather picture. Ocean Station NOVEMBER BT data were obtained from the Navy Fleet Numerical Weather Facility (FNWF) at Monterey, California. These data were in the form of daily reports which normally included from two to ten BT observations.

A point between these two ocean weather stations, which will be referred to as MIDPOINT (40N, 140W), was also included. Information for MIDPOINT, furnished by FNWF, was available for only one month.

The synoptic weather charts which were needed to estimate convergent, divergent or normal synoptic situations were obtained from records kept in the meteorology storeroom at the Naval Postgraduate School and also from the Synoptic Weather Maps (Daily Series) available through the U. S. Government Printing Office. Most of the charts used were

facsimile charts sent from the National Meteorological Center at Washington, D. C. The particular synoptic chart used included surface pressure and 1000-500 MB thickness analysis for the Northern Hemisphere.

All data collected for the verification were selected from months during which the seasonal thermocline is a prominent feature. May through August was considered the best period for this to occur at all three locations. Station PAPA data included continuous observations from May 1964 through October 1964. September and October were included to determine the method's effectiveness after the seasonal thermocline period has ended. A limited amount of observations for June 1966 were included also. The data periods for Station NOVEMBER included the following: July 1957, July through September 1958, May and June 1964, June 1965 and April through June 1966. Data for MIDPOINT were available for May 1965.

As Mazeika points out in his report, a large amount of continuous data (which must include all necessary parameters) from the same observation point is not easy to obtain. The data gathered for this verification were found in many different places and brought together so that all requirements were met. Numerous other continuous data sources had to be discarded as one or two parameters could not be located for the time period involved.

After all available data had been collected, a verification form was developed to include all the required information necessary to make proper hindcasts. This form is presented in figure 14. Most of the column headings are self-explanatory, but explanations for a few are required.

When available, windspeed was obtained from weather observations

taken concurrently with the BT observations; otherwise, it was estimated from the daily synoptic weather charts and entered on the form. Much effort was expended in making correct windspeed estimates as large errors could develop. The magnitude of this type of error was brought out earlier in this report. After windspeed was determined, Table III was entered to obtain the value η.

Next, observed mixed-layer depth was entered as the average obtained from all BT observations for that day. Since Mazeika's method predicts the <u>mean</u> mixed-layer depth it must be compared with an average value (since individual BT observations may differ greatly). Temperatures at the surface and 400 feet were averaged and then compared to obtain an accurate stability index.

After all parameters were obtained, the proper ΔT graph was used in selecting the mixed-layer thickness (thermocline depth). This value was then compared with the observed mixed-layer depth. If the observed value were larger than the predicted one, the difference between the two was entered as a negative number in the Difference column. If the predicted value were the larger of the two values, a positive number was entered in the Difference column. This was done to determine if Mazeika's method was over- or under-predicting the mixed-layer thickness in the Pacific Ocean.

When the proper criteria have been met, a check mark is placed in the column labelled Verification. In this study a tolerance of ± 20 feet from the observed value is considered to have verified. The tolerance limits were chosen after considering the factors described in the following paragraph.

First, Mazeika has shown in figure 15 that the average amplitude

of internal waves is 17.85 feet. This is interpreted to indicate that internal waves alone could provide a variation of thermocline depth of this size about its mean value. Second, Tabata and Giovando (1962) have shown this same magnitude in figure 16. They also concluded that this variation was due to internal waves. Finally, any method which can correctly predict within 20 feet of the established thermocline depth is certainly a valuable tool for the operating ASW forces.

6. Verification Results.

To insure that Mazeika's method was being applied correctly so that the results obtained would be useful, a trial run on Atlantic OWS CHARLIE was initiated. A period of one month was tested with the results presented in Table IV. The method predicted within 20 feet of the observed mixed-layer depth 63.6% of the time. This was considered acceptable, since the hindcasts were made with no previous experience on new data, although in the ocean region for which the method was developed. After this trial run, it was believed the method was being applied correctly.

Station PAPA had a total of 106 hindcasts performed during the heating period May through August. Of these, 82 were verified by the observed layer depth to show 77.4% of the hindcasts verified within 20 feet of the observed average layer depth of that day (Table V). Including those hindcasts which verified within 30 feet of the observed value increased the verification to 85%. Since the mean observed thermocline depth was approximately 100 feet (Table VI), the above percentages can be directly related to verification data presented by Mazeika (1960). These percentages are slightly higher than those which Mazeika observed on data from Stations BRAVO and DELTA in the Atlantic. However, all results obtained from Station PAPA compared favorably with what Mazeika had presented.

A monthly analysis of Station PAPA verification results presented in Tables VII, VIII, and IX shows the high success of the method during the heating season. Also shown is a rapid decline in the method's effectiveness as the cooling season begins. Table VIII indicates 46% success of prediction was experienced during the month of September and

only 21% during October. The period of seasonal or "transient" thermocline has ended and the mixed layer begins to extend to its permanent thermocline depth; this prediction method, which depends on wind and mechanical mixing, ceases to be effective since it does not include a way of accounting for convective instability in the ocean mixed layer.

Station PAPA is located in a position similar in some respects to the position of Station CHARLIE, at which Mazeika originally developed his method. The weather is quite similar in that many pressure systems, which normally consist of high winds and associated moderate to severe storms, travel eastward through this area. The mixing of the upper layers of water due to these disturbances is probably very similar at both locations. Also, the latitude of Stations CHARLIE and PAPA is very nearly the same. This would indicate that the temperature and radiation conditions are similar. Acknowledging the fact that water masses do vary greatly, the above similarities would lead one to a general acceptance that Mazeika's method should be expected to work quite well at Station PAPA.

Returning to Table V, it can be seen that Station NOVEMBER displays a completely different set of results than that of Station PAPA. NOVEMBER verified only 52 out of 191 attempts for a verification score of 27.2%. Table VI displays a mean negative value of error much higher than the mean positive value. This indicates that the method was predicting a mixed-layer depth much too shallow for the NOVEMBER area. Station NOVEMBER is in a semi-convergent mixing zone, so that the area is normally, but not continually, subjected to convergent mixing processes. The NOVEMBER area is usually under the influence of high pressure systems which move eastward. The isobar spacing in these pressure

systems is usually quite large resulting in low windspeeds. The low windspeed produces a reduced value of sea state parameter which ultimately leads to a shallower forecast of mixed-layer thickness, using Mazeika's method.

Thus the NOVEMBER area is quite different from the development area of Mazeika's method in many respects. The temperature and radiation conditions differ as well as the windspeed regimes and the overall weather patterns. These differences are believed to be the reasons for the failure of Mazeika's method in this area.

With the failure of Mazeika's method clearly evident, it was thought a test using James' version would be in order to see if the new stability index and forecasting curves might improve the results at OWS NOVEMBER. As seen in Table IV the results were also very poor. Only one month's data,previously tested using Mazeika's method, were used for this trial run.

Even with the poor results displayed, two interesting side effects were noted. First of all, obtaining the temperature gradient of the shallowest thermocline did not prove to be an easy task. From the data given in various BT reports, the gradient is determined as only a subjective estimate at best. There were some times, however, when fairly accurate gradients could be determined. These occurred when sufficient information was reported in the thermocline gradient zone. Secondly, the forecast curves of James are a much improved version compared to those of Mazeika. They are very easy to interpolate, especially at low sea state parameter values.

Since both Mazeika's method and James' version did not prove to

be successful at Station NOVEMBER, one might attempt to improve the forecasting there through a new set of curves empirically developed as was done at Station CHARLIE. This could also lead to a set of curves which would be useful at lower latitudes in general where similar conditions prevail.

In the hope of locating a transition area where the method works somewhat better than at NOVEMBER, a point approximately half-way between NOVEMBER and PAPA was tested. MIDPOINT had 27 hindcasts performed with 8 verifications for a 29.6% predictability figure (Table V). This figure indicated that one must be somewhere above 40N latitude in order for the method to work more effectively. MIDPOINT also had a large negative error value indicating that the method was still not forecasting deep enough thermocline depths.

Tully (1964) describes the behavior of the Northeast Pacific Ocean and suggests through his description where the transition between the NOVEMBER regime and PAPA regime may occur. In his paper, Tully described various domains or regions which require various models for determination of temperature structure and behavior. These domains are shown in figure 17. As can be seen MIDPOINT lies in the lower part of the Transitional Domain and Station PAPA lies in the center of the Central Subarctic Domain. Each domain is considered to have individually appropriate meteorological and oceanographic mechanisms working within it. If this is true and the study by Tully indicates this to be so, then it can be assumed that Mazeika's method should work effectively within the Central Subarctic Domain. This is not meant to limit the use of Mazeika's method but only to point out an area where high predictability reasonably may be expected.

In summary, Mazeika's method does produce effective results in the Station PAPA area and perhaps these results may be extrapolated to include the whole Central Subarctic Domain. At about 45N the method's forecast ability may begin to lessen. At MIDPOINT and Station NOVEMBER the method is less than 30% reliable, indicating the need for another consideration of the forecasting problem in this area; James' version of the forecast method did not improve results at NOVEMBER. Mazeika's method was easy to apply in most respects except for low values of η where curves are difficult to interpolate accurately. Some errors in forecast mixed-layer thickness may have occurred due to this problem.

James' version uses a stability index which may be difficult to determine in some cases. The thermocline gradient is not always clearly reported and thus must be estimated. The overall procedure is easy to use, especially with regard to James' forecasting curves which offer many improvements over the earlier Mazeika version.

7. Verification of Climatology Results.

For the determination of stability index Mazeika suggested as a source climatology data (monthly or seasonal) which gives the temperature at the surface and 400 feet. Since actual BT data were used for the determination of stability index in this report, a comparison of the two was considered for a reliability check of the climatology data.

Only certain areas have been studied thoroughly enough to produce such data. One of these areas is the Gulf of Alaska in the Northeast Pacific Ocean. Margaret K. Robinson (1957) of Scripps Institution of Oceanography conducted a study of sea temperature for this area. Robinson analyzed 16,103 individual BT observations from the period 1941 to 1952. The BT data were subjected to extrapolation, interpolation and visual smoothing to obtain the various monthly averages.

Figures 18 and 19 show one version of the temperature averaging results. These charts can be used to obtain a monthly average stability index. However, a different version may be more accurate for determining temperature from a day-to-day or week-to-week basis. This version is displayed in figure 20. This graphical summary was used to obtain the temperature data for the comparison.

Temperatures for the surface and 400 feet were taken from figure 20 for the months of May through October. These were compared against BT observation averages which resulted from this verification report. The results have been tabulated and are presented in Table X.

It must be pointed out that figure 20 is a summary of data for 49N, 148W which is slightly southwest of Station PAPA. All temperatures taken from figure 20 were slightly higher than those which might be expected at PAPA, but a comparison should still prove valuable.

Since data from Station PAPA were available for the last half of May only, Table X includes the averages for this period only. It can be seen that the averages compare quite well and in most cases would result in using the same forecasting curve for Mazeika's method. These averages ought to be even closer if both were done for the same observation point.

From this comparison it is evident that climatology data can be used effectively in determining accurate stability indexes in Mazeika's thermocline depth forecasts.

8. Conclusions and Recommendations.

Mazeika's method of thermocline depth prediction does work effectively at Station PAPA. The method predicted within 20 feet of the observed mixed-layer depth 77.4% of the time. This is considered to be a good prediction percentage.

From the study conducted by Tully, it can be assumed the same success experienced at Station PAPA may be realized for the entire Central Subarctic Domain. This is due to the consistent meteorological and oceanographic properties of this area.

Station NOVEMBER offered little success with either the Mazeika or James version. Both predicted within 20 feet of the thermocline depth less than 30% of the time.

The verification attempt at MIDPOINT resulted in less than 30% prediction success also. The success of Mazeika's method at PAPA and the failure of it at NOVEMBER and MIDPOINT is primarily due to weather and environmental conditions. The temperature, radiation conditions, wind regime and weather similarities with regard to Station PAPA and the development area of Mazeika's method leads one to believe the method should work under these similar conditions. At Station NOVEMBER and MIDPOINT the conditions are not the same thus causing the method to fail. It is believed that forecasting curves could be developed for this area which would make the method useful here.

During the verification process it was found that Mazeika's forecasting curves were difficult to interpolate at low sea state parameter values. This difficulty may lead to errors in mixed-layer depth prediction. All other parameters and procedures were considered very easy to use. This method should be adaptable to fleet-wide distribution for use in anti-submarine operations.

James' version of Mazeika's method was also easy to use, with the exception of the stability index. James' thermocline gradient is more difficult to determine than the temperature difference which Mazeika uses. The forecasting curves developed by James are much easier to use and provide for a more accurate mixed-layer forecast.

Climatology data which may be used to determine the stability index for Mazeika's procedure were also tested. The results indicated that climatology data supply accurate information for this determination.

9. Acknowledgements.

I am grateful for the help in obtaining data to Dr. T. Laevastu and Mr. H. P. Parks of the Fleet Numerical Weather Facility. I am further indebted for assistance, encouragement, and advice to Professor Glenn H. Jung, my faculty advisor. To my wife, Lynda, my appreciation and gratitude for both moral and practical support.

BIBLIOGRAPHY

1. Hubert, W. E. and T. Laevastu. Analysis and Prediction of the Depth of the Thermocline and Near-Surface Thermal Structure. Fleet Numerical Weather Facility, Monterey, California. Technical Note No. 10, August, 1965.

2. James, R. W. Ocean Thermal Structure Forecasting. SP-105 ASWEPS Manual Series, Volume 5, U. S. Naval Oceanographic Office, 1966.

3. Mazeika, P. A. Prediction of the Thermocline Depth. U. S. Naval Oceanographic Office. Technical Report 104, ASWEPS Report No. 5, June, 1960.

4. Pierson, W. J., Neumann, G., and James, R. W. Practical Methods for Observing and Forecasting Ocean Waves by Means of Wave Spectra and Statistics, U. S. Navy Hydrographic Office Publication No. 603, 1955.

5. Robinson, M. K. Sea Temperature in the Gulf of Alaska and in the Northeast Pacific Ocean, 1941-1952. Bulletin of the Scripps Institution of Oceanography of the University of California, LaJolla, California. Volume 7, No. 1, 1957.

6. Tabata, S. and L. F. Giovando. Prediction of Transient Temperature Structure in the Surface Layers of the Ocean. Fisheries Research Board of Canada, Manuscript Report Series No. 132, June 1962.

7. Tully, J. P. Oceanographic Regions and Assessment of Temperature Structure in the Seasonal Zone of the North Pacific Ocean. Fisheries Research Board of Canada, Volume 21, No. 5, 1964.

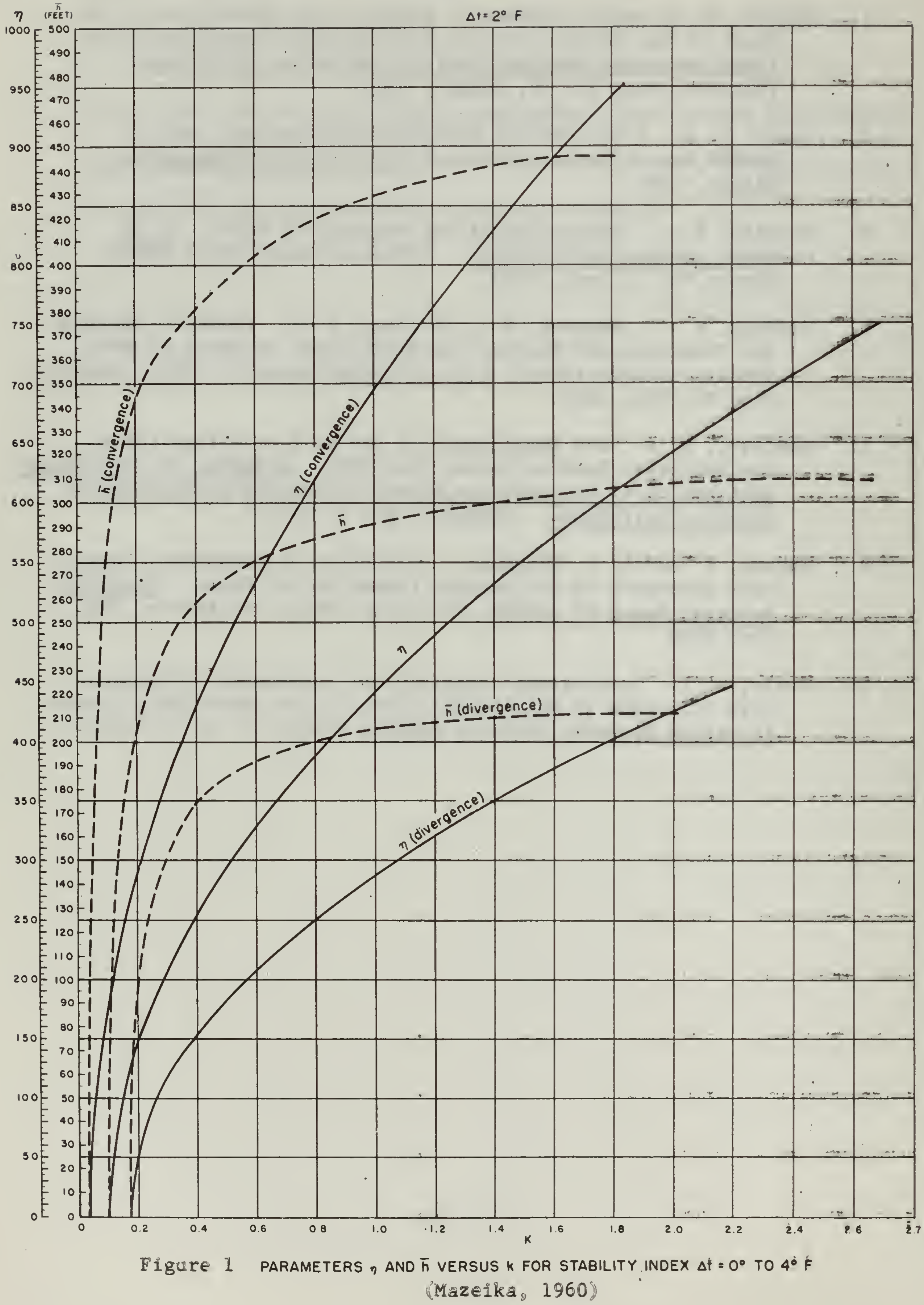


Figure 1 PARAMETERS η AND $\bar{h}$ VERSUS k FOR STABILITY INDEX Δt = 0° TO 4° F
(Mazeika, 1960)

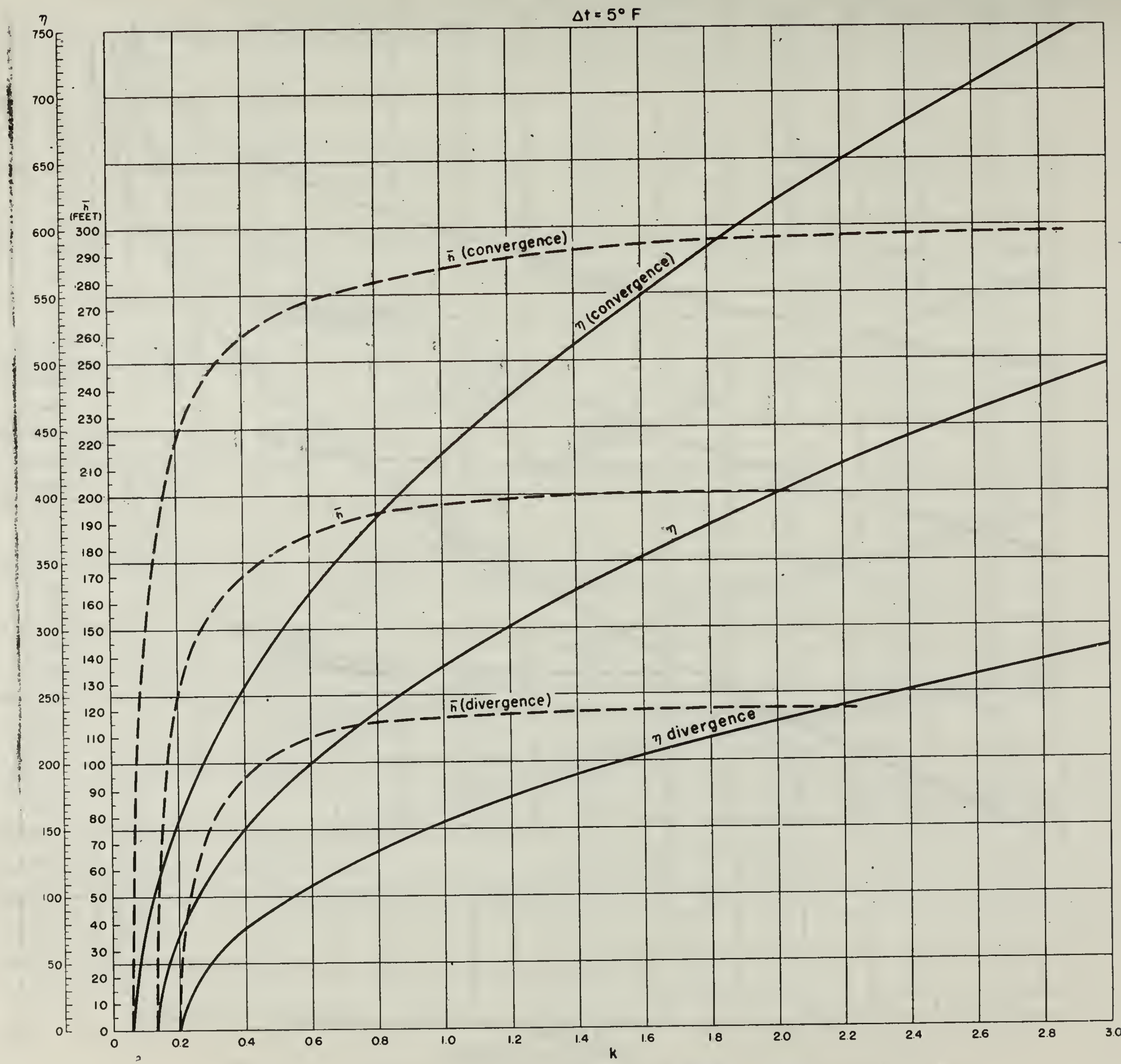


Figure 2 PARAMETERS η AND $\bar{h}$ VERSUS k FOR STABILITY INDEX Δt = 4° TO 6° F
(Mazeika, 1960)

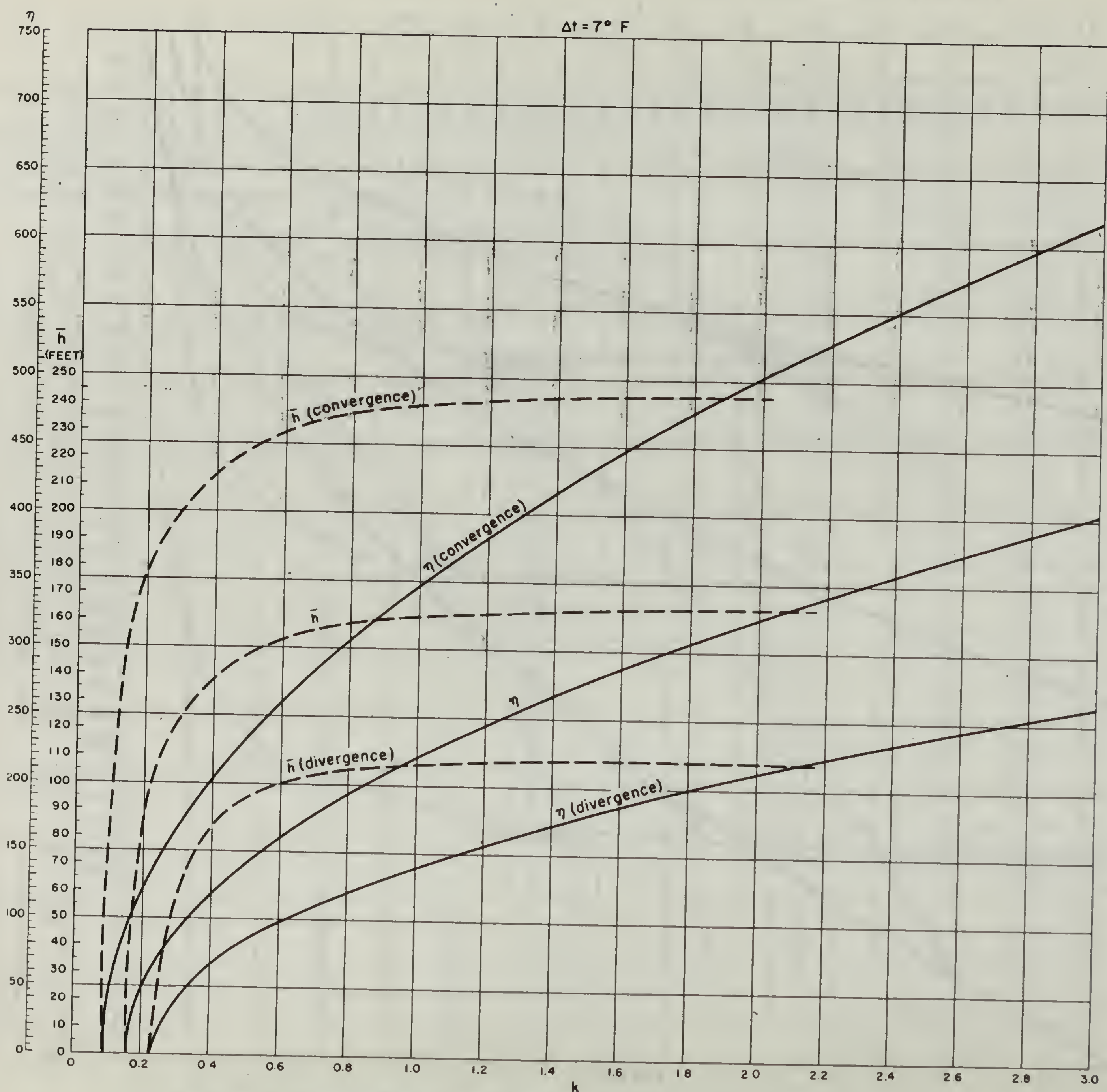


Figure 3 PARAMETERS η AND $\bar{h}$ VERSUS k FOR STABILITY INDEX $\Delta t = 6°$ TO $8°$ F

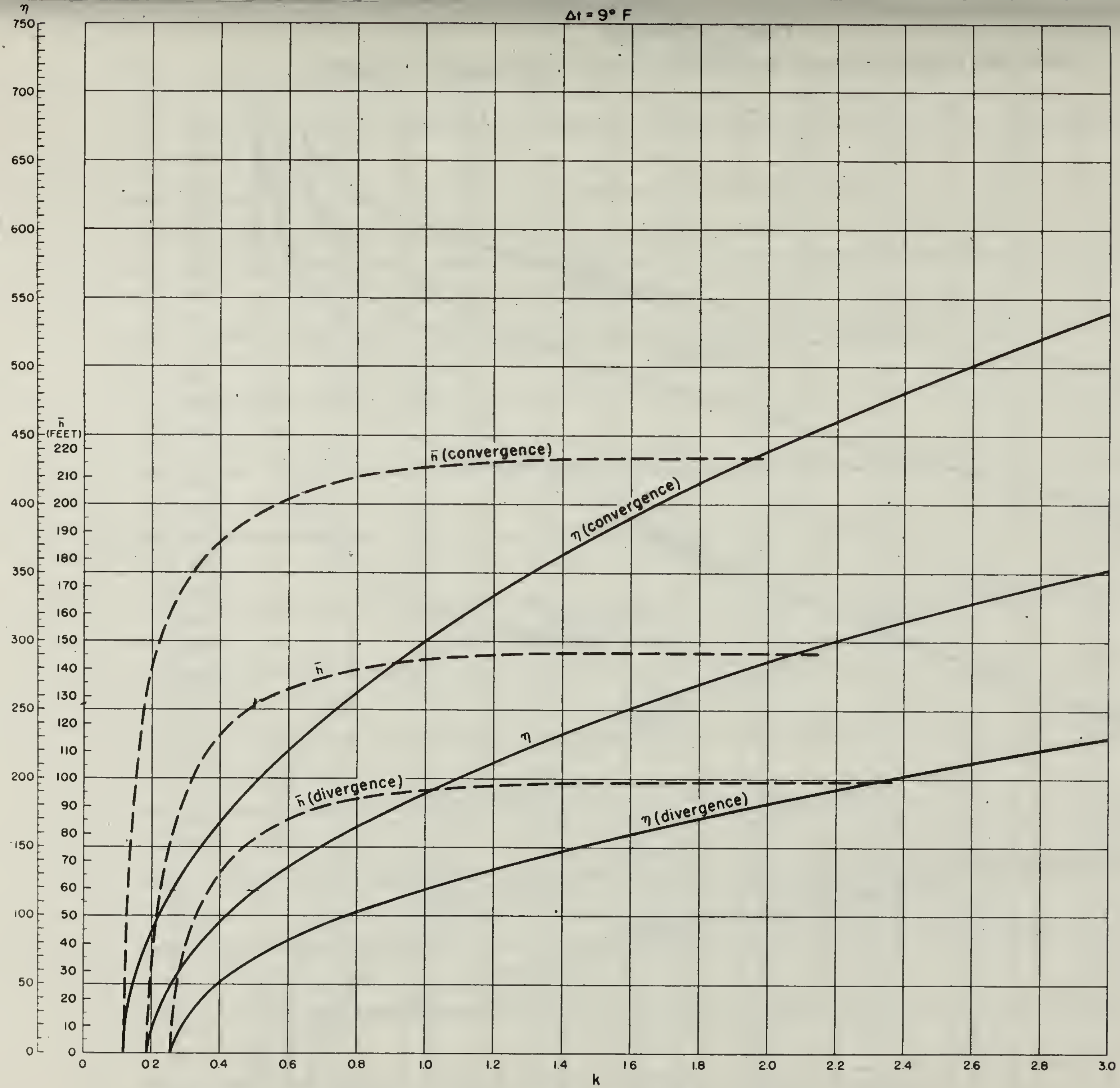


Figure [illegible] PARAMETERS η AND $\bar{h}$ VERSUS k FOR STABILITY INDEX Δt = 8° TO 10° F

(Mazeika, 1960)

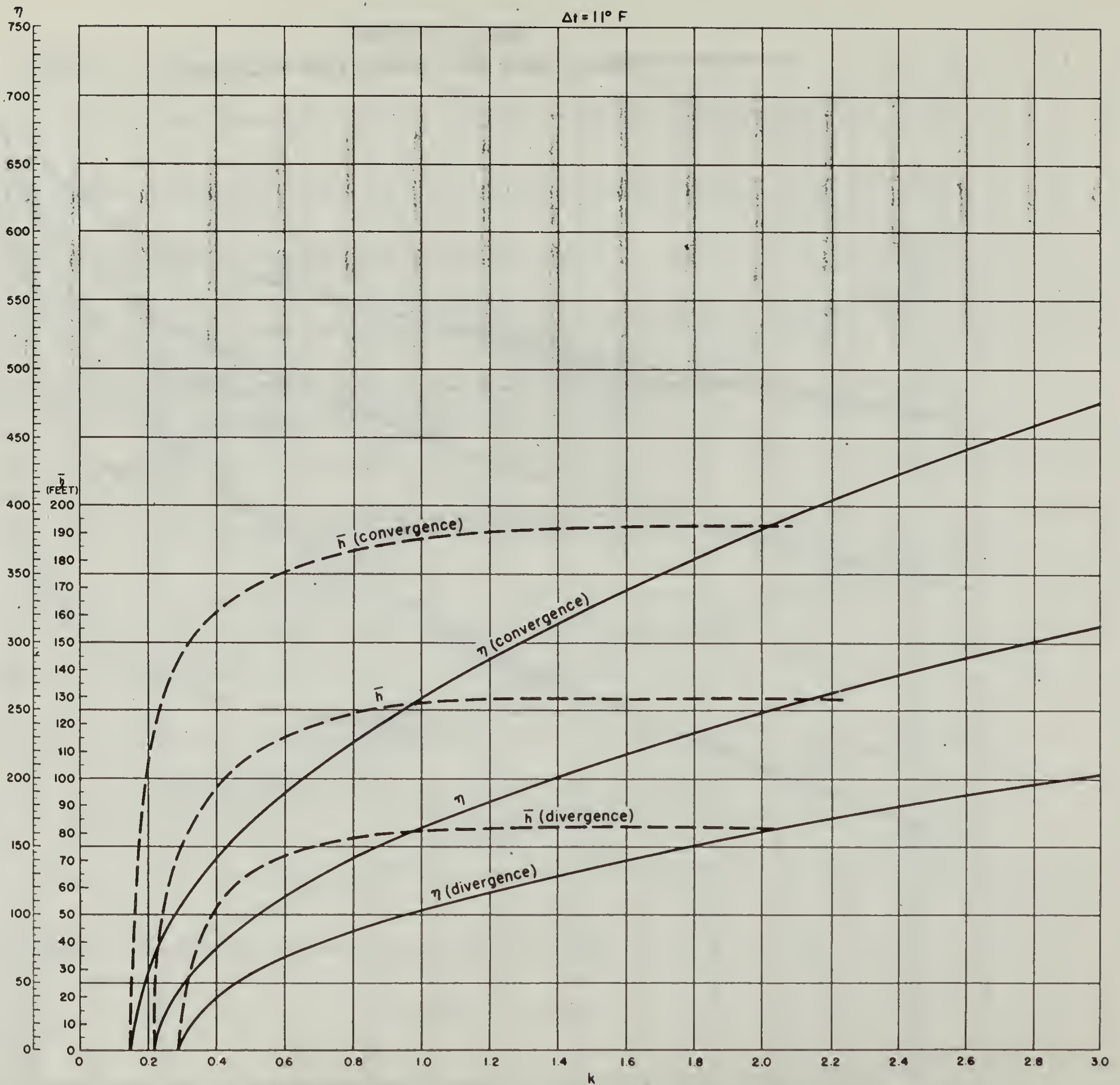


Figure 5 : PARAMETERS η AND $\bar{h}$ VERSUS k FOR STABILITY INDEX Δt = 10° TO 12° F

(Mazeika, 1960)

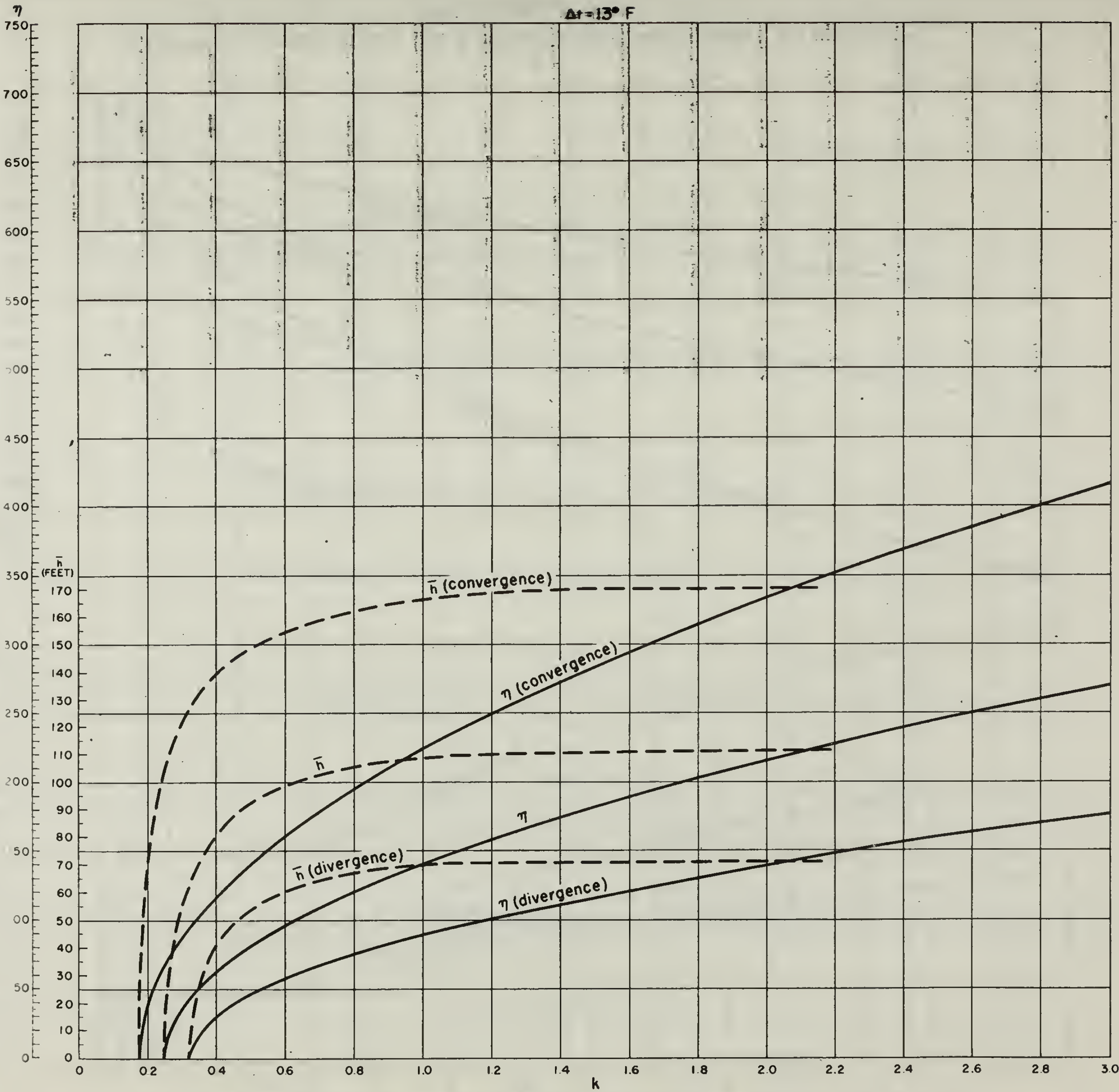


Figure 6. PARAMETERS η AND $\bar{h}$ VERSUS k FOR STABILITY INDEX Δt = 12° TO 14° F

(Mazeika, 1960)

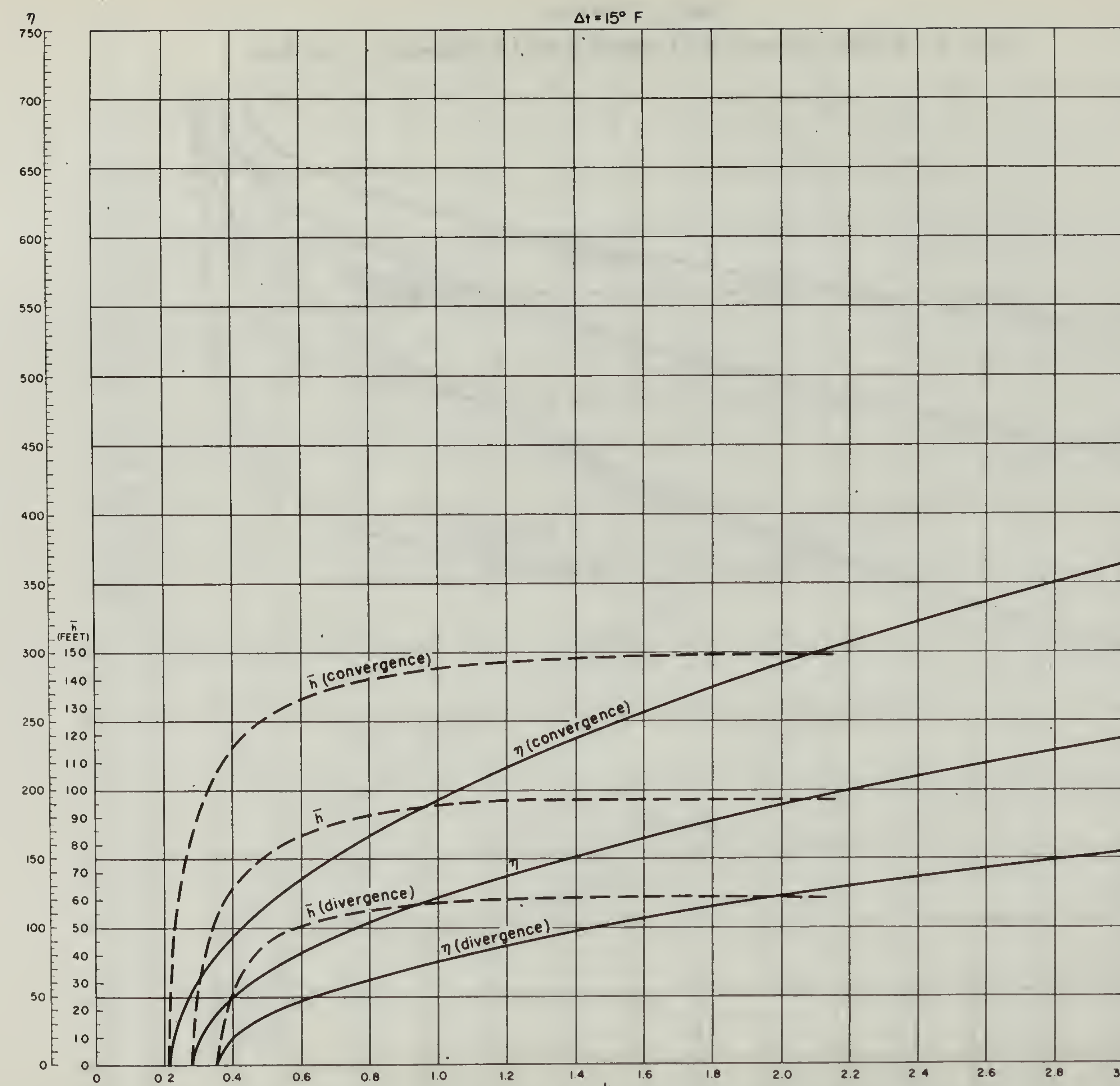


Figure 7 PARAMETERS η AND $\bar{h}$ VERSUS k FOR STABILITY INDEX Δt = 14° TO 16° F (Mazeika, 1960)

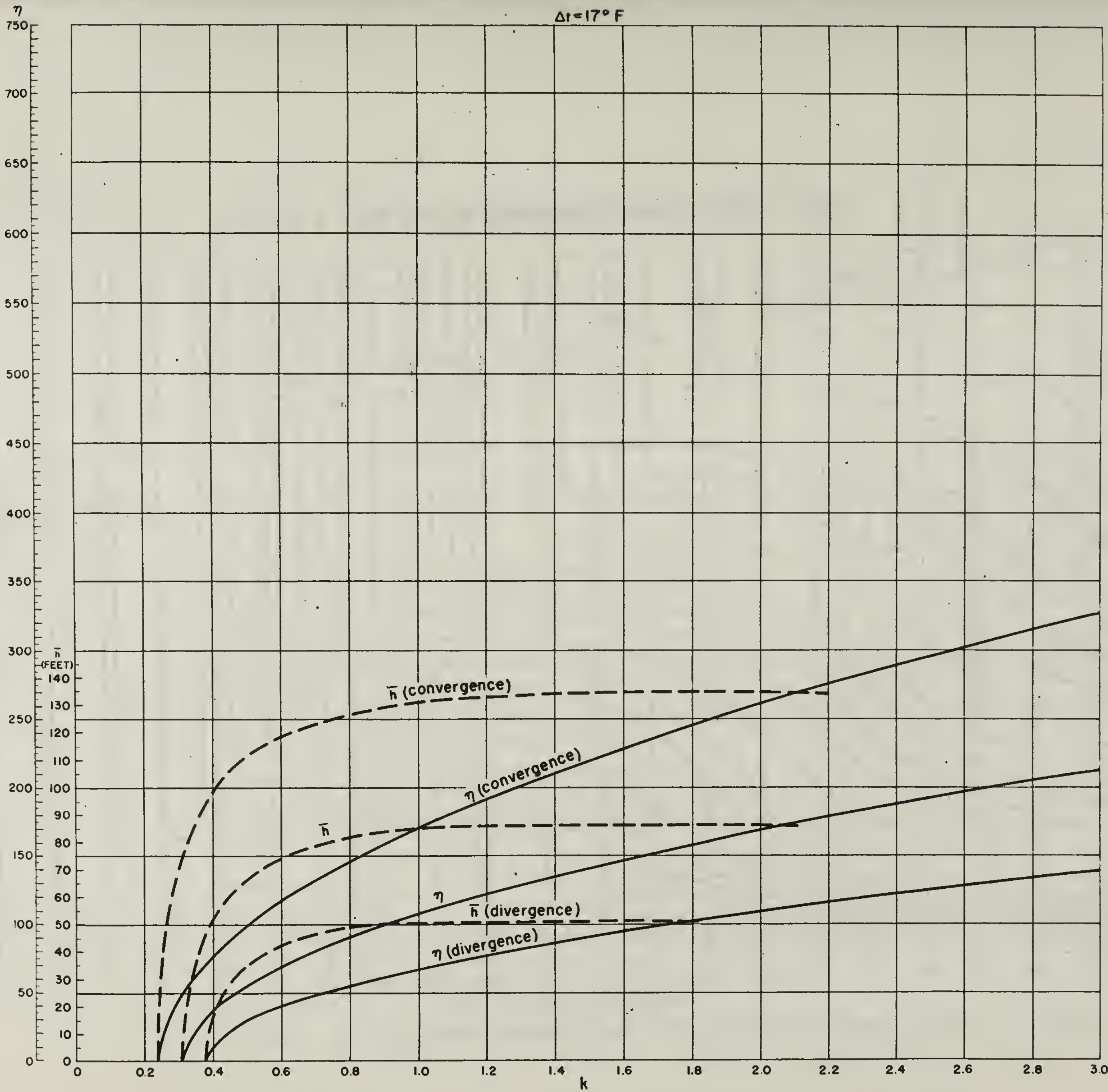


Figure 8 PARAMETERS η AND $\bar{h}$ VERSUS k FOR STABILITY INDEX Δt = 16° TO 18° F

(Mazeika, 1960)

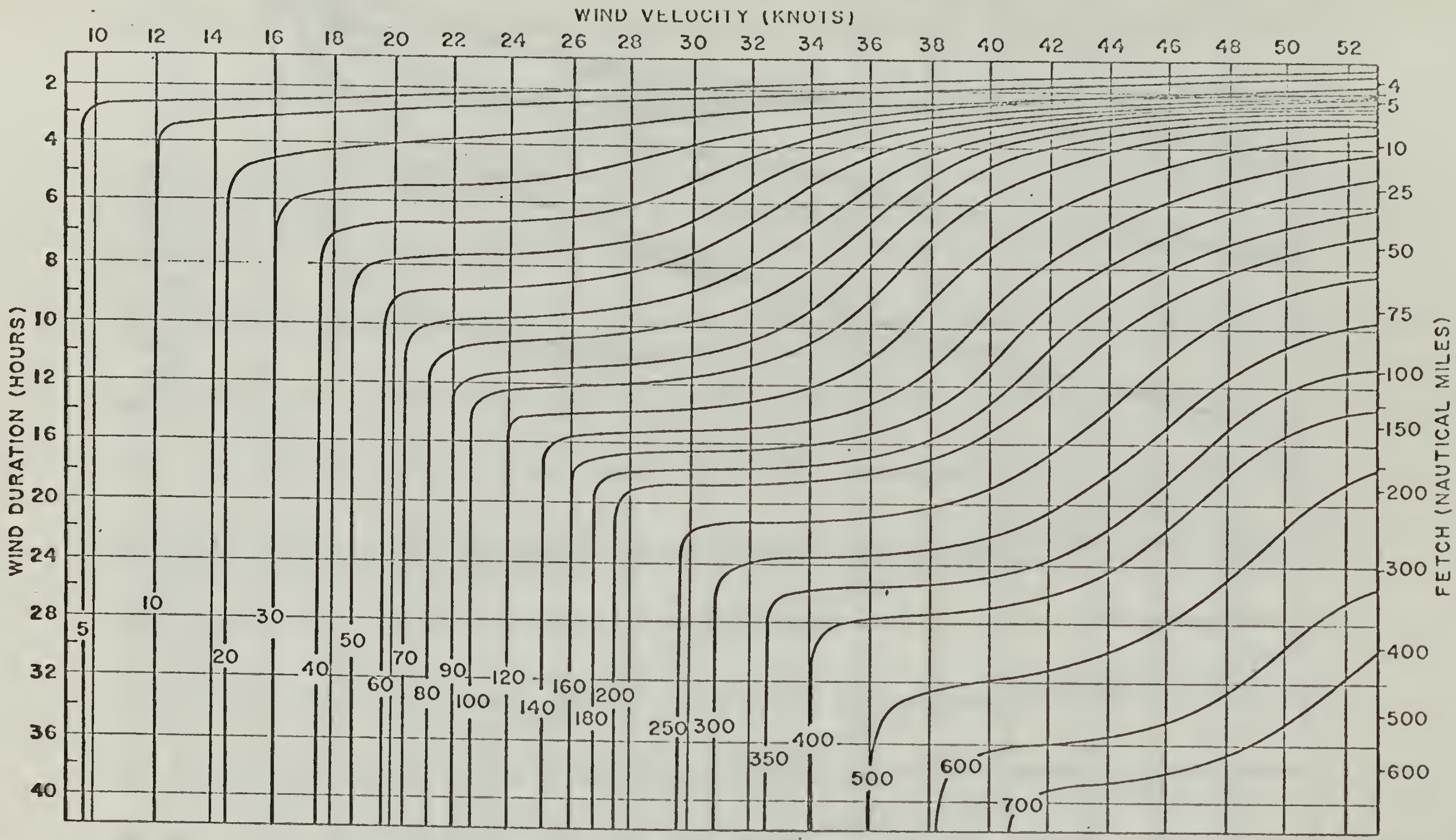


Figure 9 SEA STATE PARAMETER GRAPH (James, 1966)

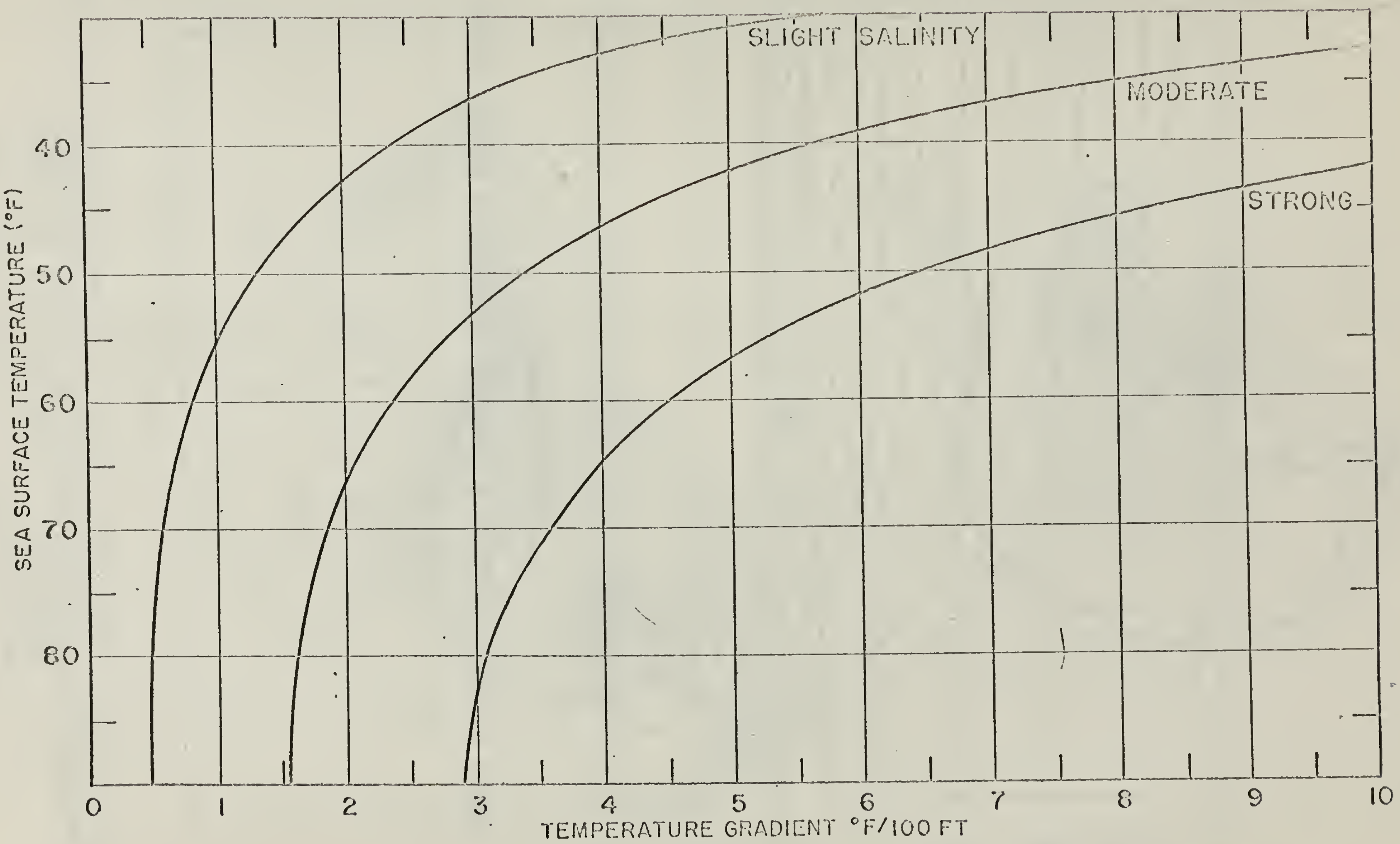


Figure 10 SALINITY CORRECTIONS FOR CONVECTIVE MIXING (James, 1966)

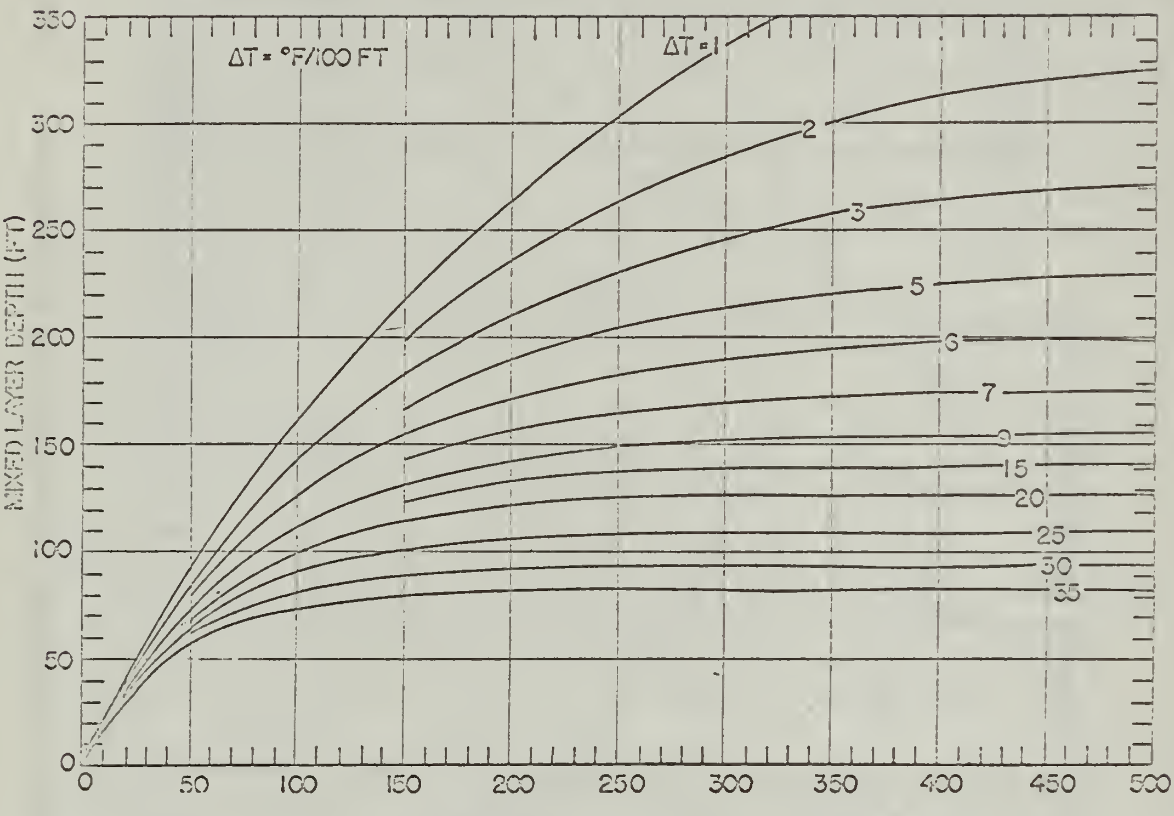
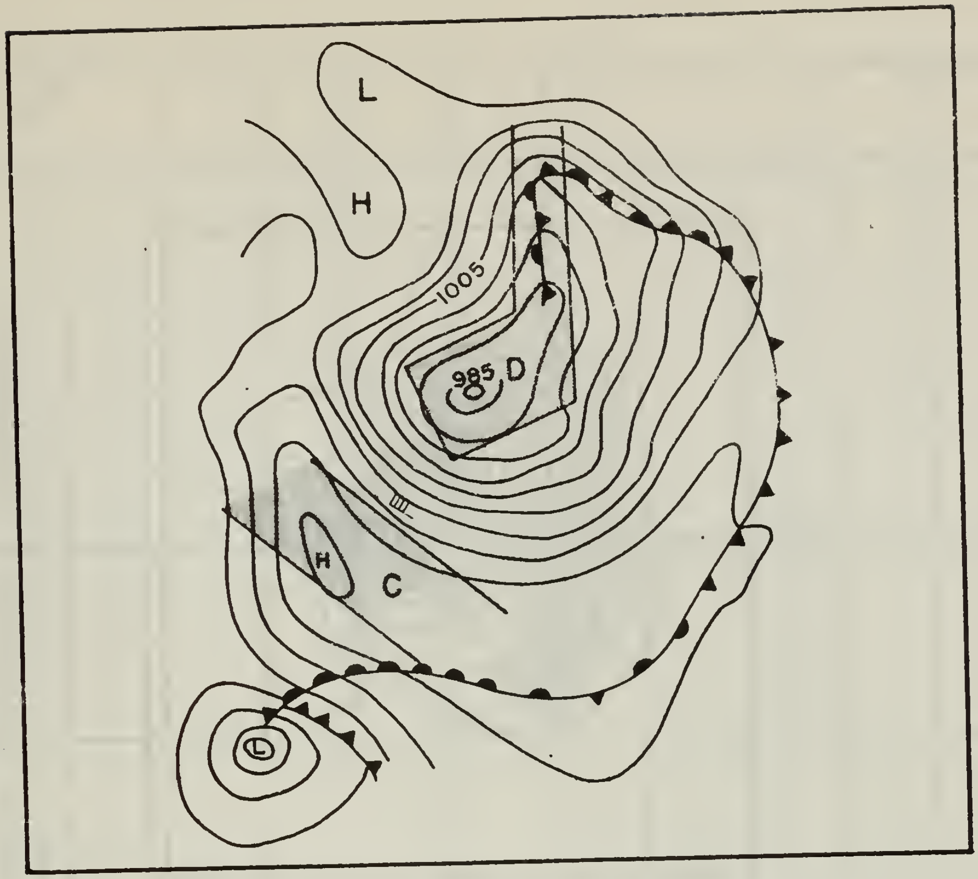
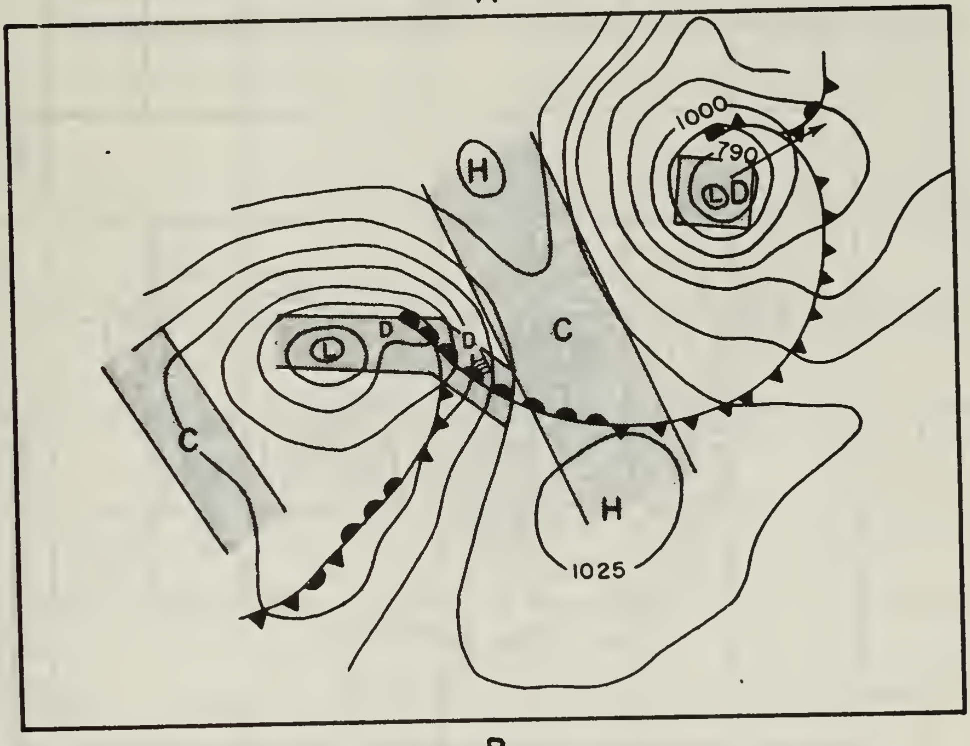


Figure 11 LAYER DEPTH AS A FUNCTION OF TURBULENT MIXING (James, 1966)



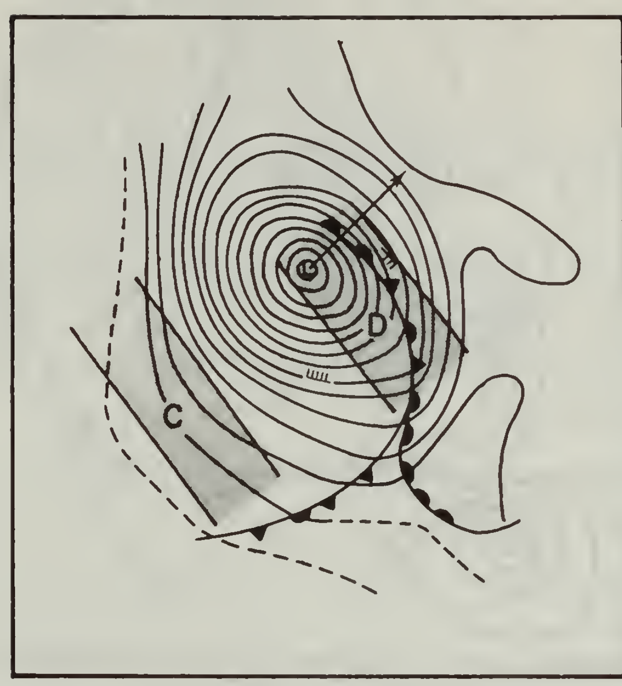
A



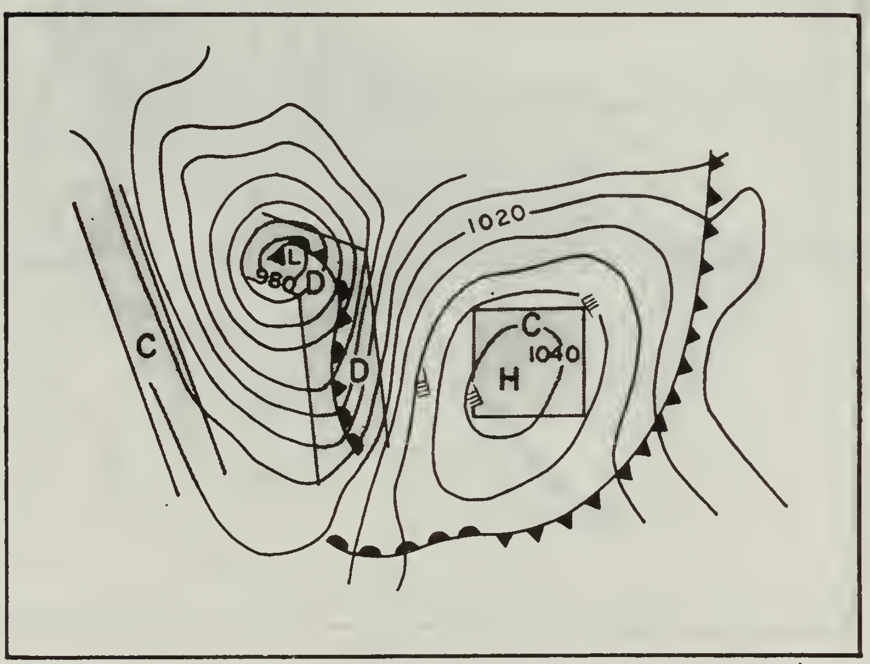
B

Figure 12 RELATIONSHIP OF TYPICAL ASSUMED CONVERGENT AND DIVERGENT FIELDS AS APPLIED TO PRESSURE SYSTEMS FOR CHOICE OF η CURVES
(C = CONVERGENCE, D = DIVERGENCE)

(Mazeika, 1960)



A



B

Figure 13 RELATIONSHIP OF TYPICAL ASSUMED CONVERGENT AND DIVERGENT FIELDS AS APPLIED TO PRESSURE SYSTEMS FOR CHOICE OF η CURVES (C = CONVERGENCE, D = DIVERGENCE)

(Mazeika, 1960)

VERIFICATION FORM

SERIAL	DAY	WIND SPEED	CONV NORM DIV	SFC TEMP	400' TEMP	ΔT	η	Predicted Mixed Layer Depth	Observed Mixed Layer Depth	Difference	REMARKS	Verification

Figure 14

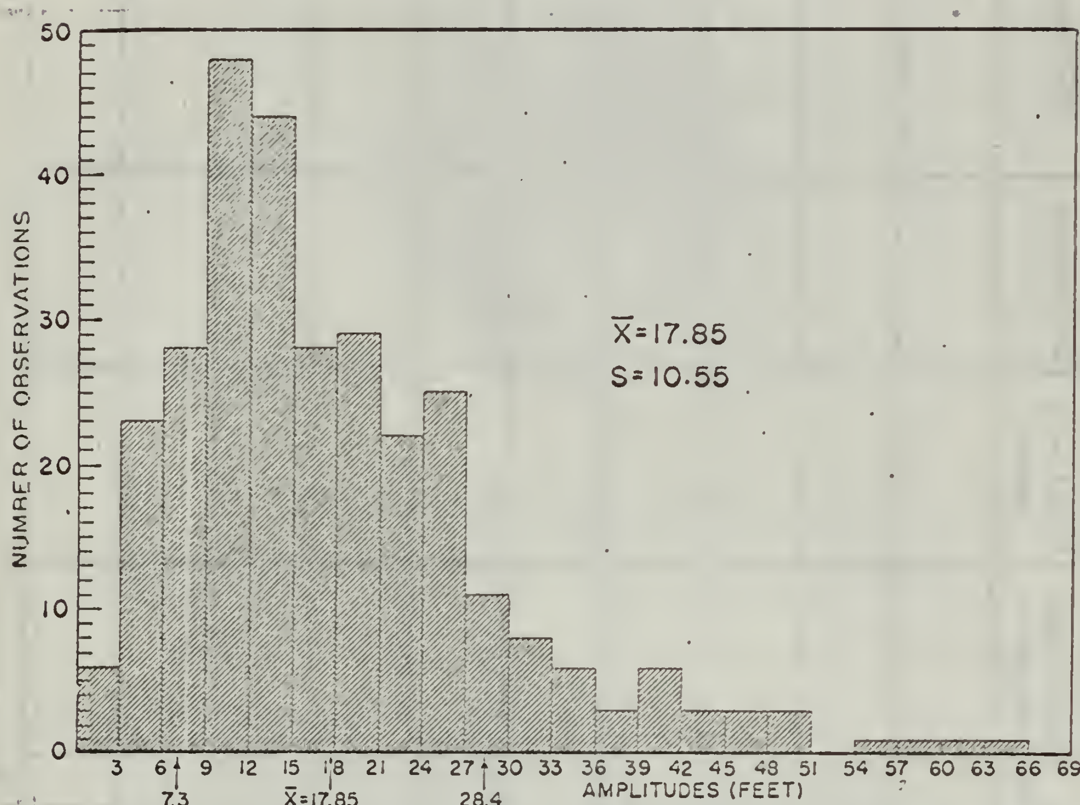


Figure 15 AMPLITUDES OF INTERNAL WAVES: FREQUENCY DISTRIBUTION, MEAN, AND STANDARD DEVIATION. (OBS. 300)

(Mazeika, 1960)

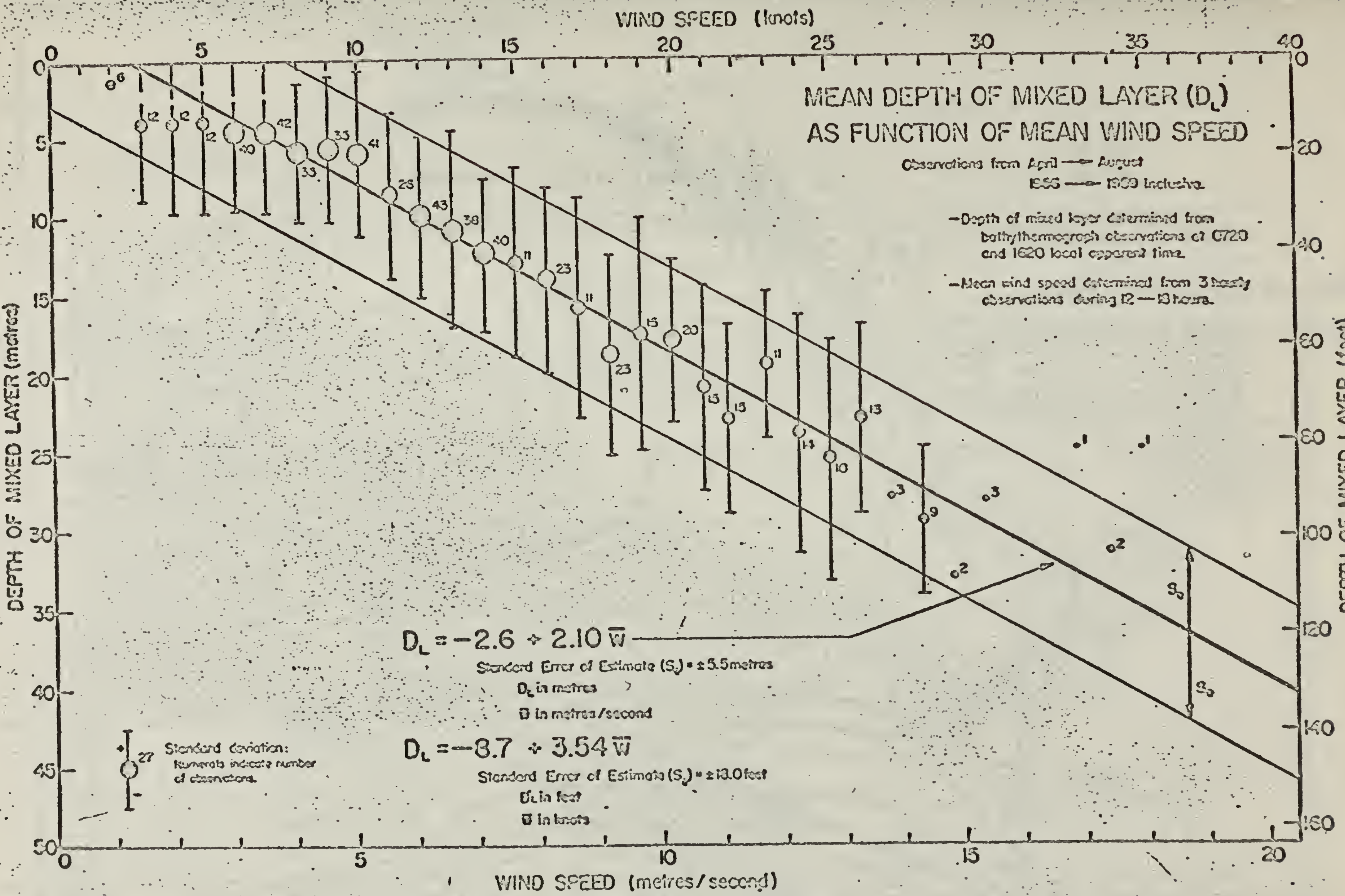


Figure 16 (Tabata and Giovando, 1962)

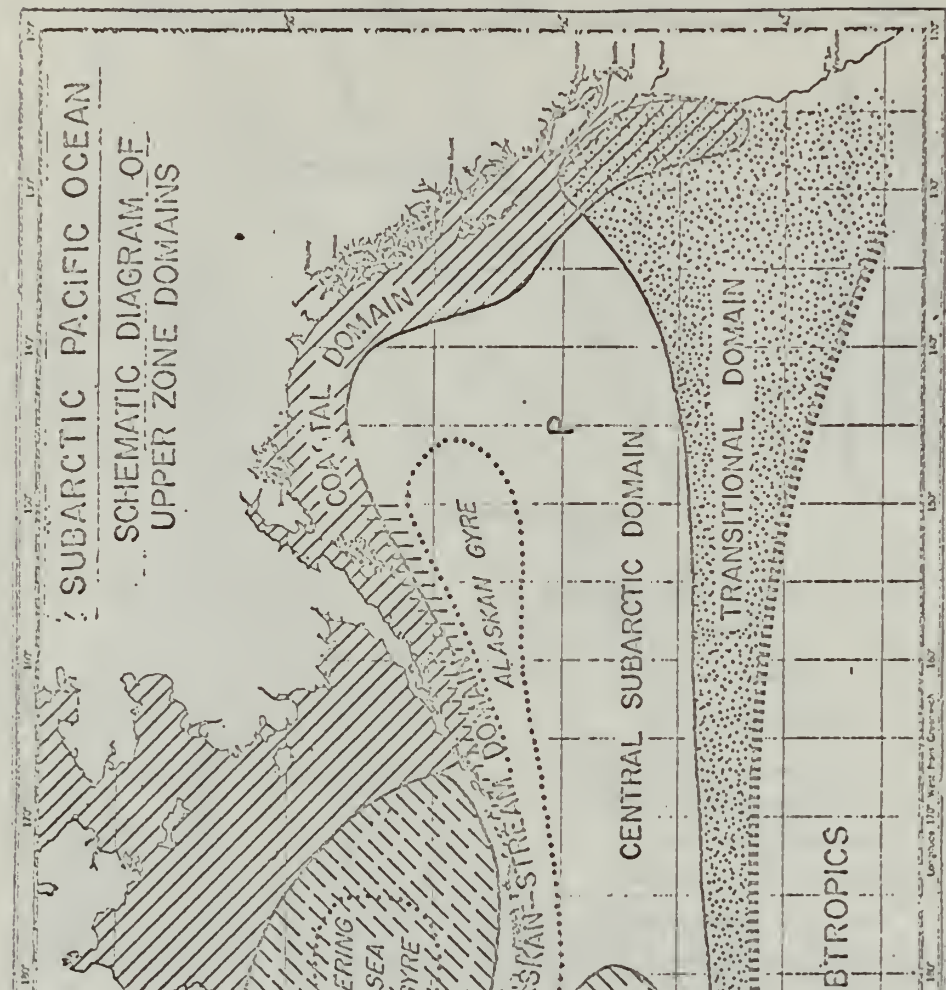


Figure 17 (Tully, 1964)

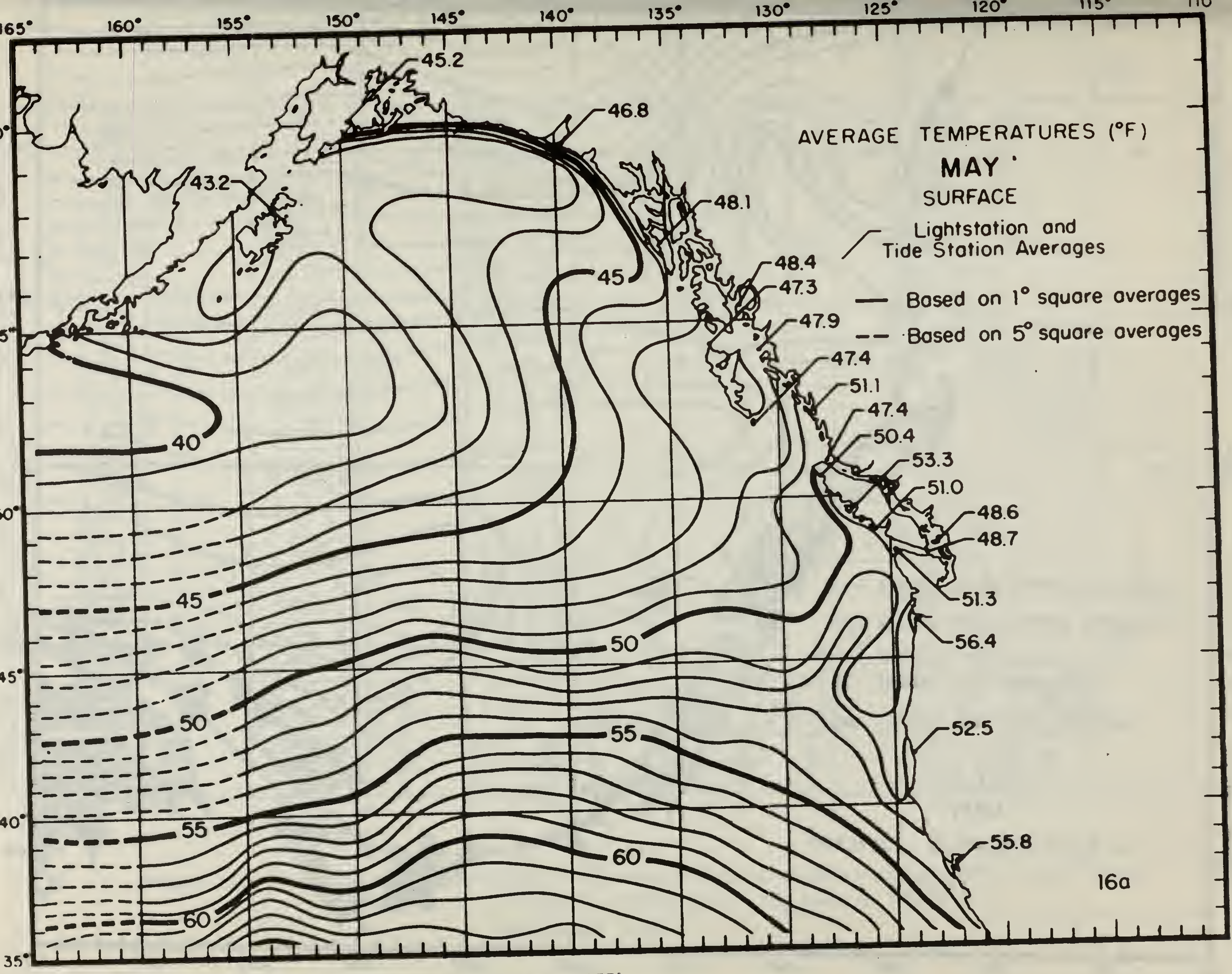
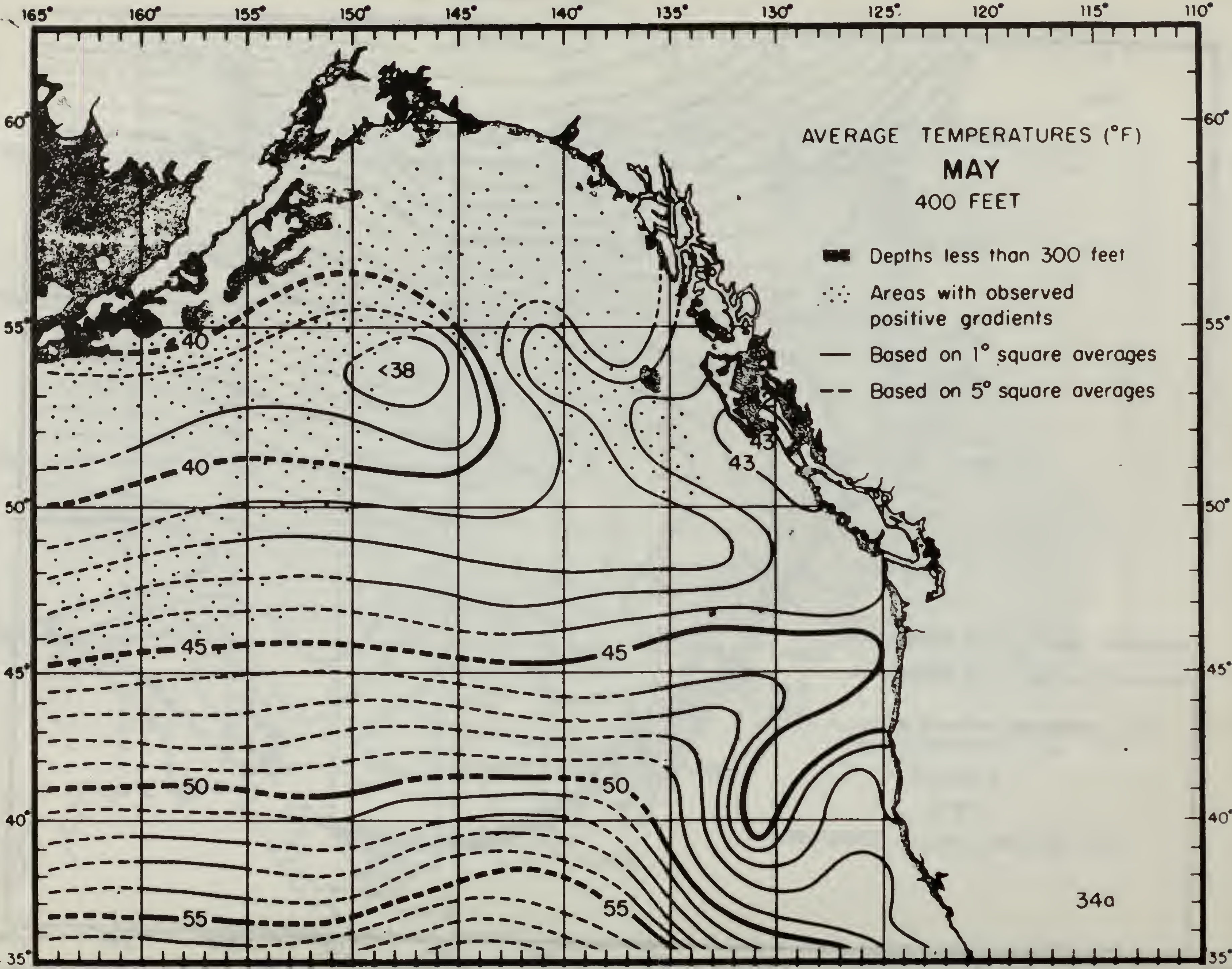


Figure 18 (Robinson, 1957)


AVERAGE TEMPERATURES (°F)
MAY
400 FEET
Depths less than 300 feet
Areas with observed positive gradients
Based on 1° square averages
Based on 5° square averages
34a
<38
40
43
45
50
55
165° 160° 155° 150° 145° 140° 135° 130° 125° 120° 115° 110°
60° 55° 50° 45° 40° 35°

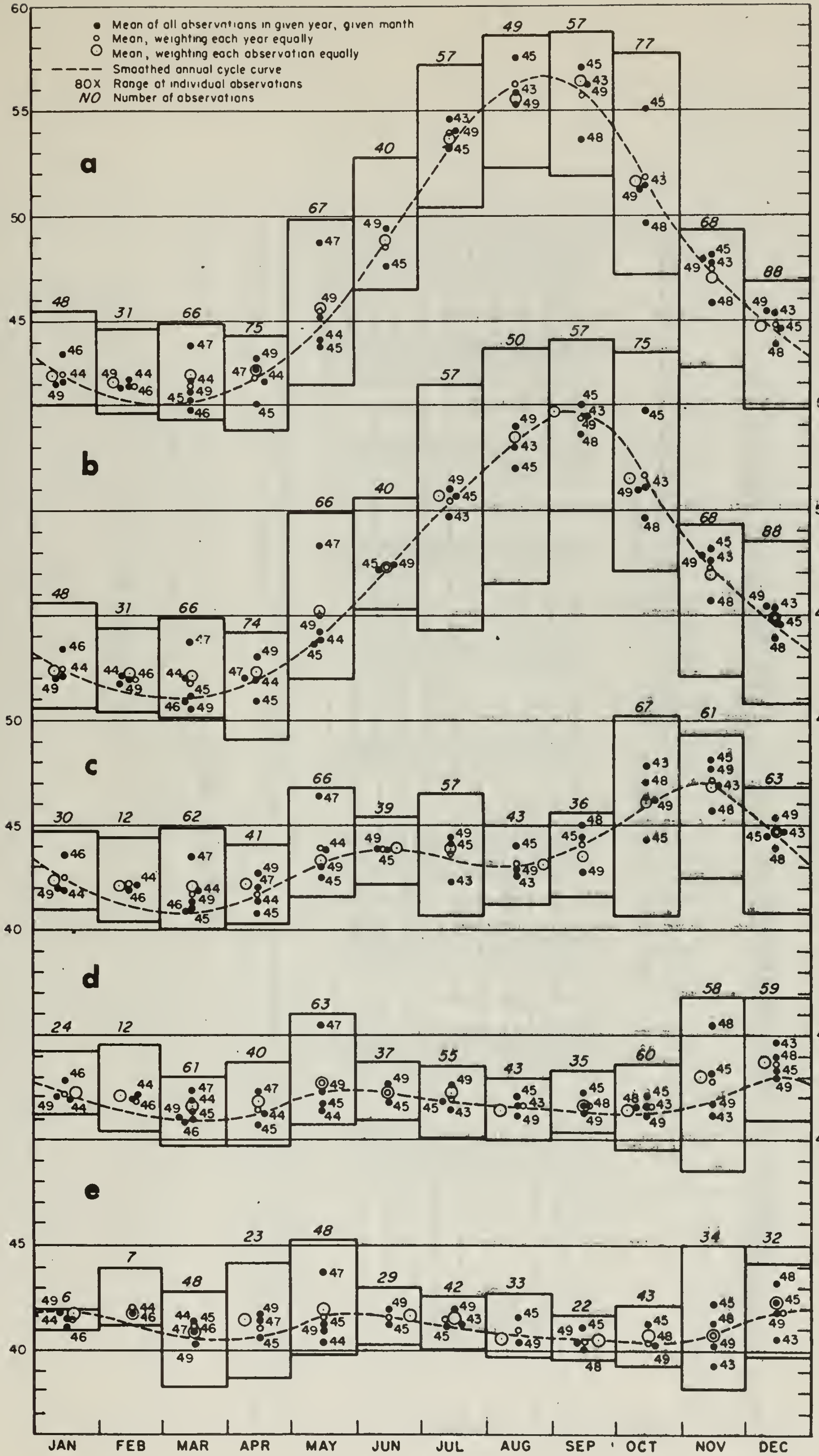


Figure 20. Graphical summary of BT temperature data at weather station, 49° N, 148° W: a. surface; b. 100 feet; c. 200 feet; d. 300 feet; e. 400 feet.

(Robinson, 1957)

TABLE I

CORRECTION OF STABILITY INDEXES FOR SALINITY DIFFERENCE IN THE THERMOCLINE

MEAN TEMPERATURE IN THE THERMOCLINE (^{o}F)	CORRECTION* $\Delta t'$ (^{o}F)									
	1	2	3	4	5	6	7	8	9	10
	SALINITY DIFFERENCE (^{o}/oo) IN THE THERMOCLINE									
35	0.06	0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.54	0.60
40	0.08	0.16	0.24	0.32	0.40	0.48	0.56	0.64	0.72	0.80
45	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
50	0.12	0.24	0.36	0.48	0.60	0.72	0.84	0.96	1.08	1.20
55	0.14	0.28	0.42	0.56	0.70	0.84	0.98	1.12	1.26	1.40
60	0.16	0.32	0.48	0.64	0.80	0.96	1.12	1.28	1.44	1.60
65	0.18	0.36	0.54	0.72	0.90	1.08	1.26	1.44	1.62	1.80
70	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00
75	0.22	0.44	0.66	0.88	1.10	1.32	1.54	1.76	1.98	2.20
80	0.24	0.48	0.72	0.96	1.20	1.44	1.68	1.92	2.16	2.40
85	0.26	0.52	0.78	1.04	1.30	1.56	1.82	2.08	2.34	2.60

*If salinity increases with depth, the correction is positive and is reduced by 1^{o} F. If salinity decreases with depth, the correction is negative and is increased by 1^{o} F. No correction is applied if $\Delta t'$ equals 1^{o} F.

(Mazeika, 1960)

TABLE II

Duration for Wind Mixing to Stabilize

Sea State Parameter	Time required is
0-15	3 hrs
16-30	6
31-50	9
51-80	12
81-120	15
121-170	18
>170	24

(James, 1966)

TABLE III

WIND AND SEA SCALE FOR FULLY DEVELOPED SEA
(Mazeika, 1960)

Beaufort Force	Wind Speed (knots)	Significant Height $H_{1/3}$ (feet)	Period of Maximum Energy of Spectrum T_{max}	Wave Length $\lambda = 3.41T^2_{max}$ (feet)	η	Minimum Fetch (nautical miles)	Minimum Duration (hours)
3	8.5	1.0	3.4	40	3.4	9.8	1.7
	10	1.4	4.0	55	6	10	2.4
	11	1.8	4.4	66	8	14	3.1
	12	2.2	4.8	79	11	18	3.8
4	13	2.7	5.2	92	14	23	4.5
	14	3.3	5.6	107	19	28	5.2
	15	4.1	6.1	125	23	34	5.9
	16	4.6	6.5	144	30	40	6.6
	17	5.4	6.9	162	37	48	7.5
5	18	6.1	7.2	176	44	55	8.3
	19	6.9	7.7	202	53	65	9.2
	20	8.0	8.1	224	65	75	10.0
	21	9.0	8.5	246	77	88	11.0
	22	10.0	8.9	270	89	100	12.0
	23	11.0	9.3	295	102	115	13.0
6	24	12.0	9.7	320	116	130	14.0
	25	13.7	10.2	355	140	155	15.5
	26	15.0	10.5	376	157	180	17.0
	27	16.0	10.9	405	180	205	18.5
	28	18.0	11.3	436	203	230	20.0
	29	20.0	11.7	467	236	255	21.5
7	30	22.0	12.1	499	266	280	23.0
	31	23.7	12.6	542	298	310	25.0
	32	26.0	12.9	567	336	340	27.0
	33	28.0	13.3	604	372	380	28.5
	34	30.0	13.6	631	408	420	30.0
	35	32.5	14.1	679	458	460	32.0
	36	35.0	14.5	718	508	500	34.0
8	37	37.0	14.9	758	551	530	37.0
	38	40.0	15.4	810	615	600	38.0
	39	42.5	15.8	850	671	655	40.0
	40	45.0	16.1	885	725	710	42.0
	41	47.5	16.6	940	788	770	44.5
	42	50.0	17.0	986	850	830	47.0
	43	54.0	17.4	1030	940	895	49.5
9	44	58.0	17.7	1070	1027	960	52.0
	45	61.0	18.2	1130	1110	1035	54.5
	46	64.0	18.6	1180	1190	1110	57.0

TABLE IV

FREQUENCY OF PREDICTION ERRORS OF THERMOCLINE DEPTH AT STATIONS CHARLIE (52.8N, 35.5W) and NOVEMBER (30N, 140W)

CHARLIE			NOVEMBER(James' Method)		
Difference between predicted and observed thermocline depth (ft)	Number of predictions and hindcasts	Percent of total	Difference between predicted and observed thermocline depth (ft)	Number of predictions and hindcasts	Percent of total
5	9	40.9			
10	9	40.9	10	1	4.6
15	11	50.0	15	1	4.6
20	14	63.6	20	2	9.1
30	14	63.6	30	3	13.6
30	8	36.4	30	19	86.4
	22			22	

TABLE V

FREQUENCY OF PREDICTION ERRORS OF THERMOCLINE DEPTH AT STATIONS PAPA (50N, 145W) NOVEMBER (30N, 140W) and MIDPOINT (40N, 140W)

PAPA			NOVEMBER			MIDPOINT		
Difference between predicted and observed thermocline depth (ft)	Number of predictions and hindcasts	Percent of total	Difference between predicted and observed thermocline depth (ft)	Number of predictions and hindcasts	Percent of total	Difference between predicted and observed thermocline depth (ft)	Number of predictions and hindcasts	Percent of total
<5	23	21.7						
<10	45	42.5	<10	38	19.9	<10	4	14.8
<15	66	62.3	<15	45	23.6	<15	8	29.6
≤ 20	82	77.4	≤ 20	52	27.2	≤ 20	8	29.6
<30	90	84.9	<30	59	30.9	<30	14	51.9
>30	16	15.1	>30	132	69.1	>30	13	48.1
106			191			27		

TABLE VI

MEAN VALUES OF PREDICTION ERRORS

Station	Mean observed thermocline depth (ft)	Mean neg. value of prediction error (ft)	Mean abs. value of prediction error (ft)	Mean pos. value of prediction error (ft)	Mean error from observed (percent)	No. of neg. errors	No. of pos. errors
PAPA[a]	95.4	18.9	15.1	10.8	15.8	64	36
NOVEMBER[b]	120.1	92.2	69.9	30.6	58.2	124	63
MIDPOINT[c]	39.3	28.5	27.8	10.0	70.8	26	1
CHARLIE[d]	59.1	20.0	38.1	40.9	64.5	1	22
NOVEMBER[e] (James)	129.6	84.0	80.8	15.0	62.4	21	1

a May, June, July and August only
b April, May, June, July, August and September

c May only
d Atlantic OWS
e One month redone using James' version

TABLE VII

FREQUENCY OF PREDICTION ERRORS OF THERMOCLINE DEPTH AT STATION PAPA FOR MAY[a], JUNE[b], and JULY

MAY			JUNE			JULY		
Difference between predicted and observed thermocline depth (ft)	Number of predictions and hindcasts	Percent of total	Difference between predicted and observed thermocline depth (ft)	Number of predictions and hindcasts	Percent of total	Difference between predicted and observed thermocline depth (ft)	Number of predictions and hindcasts	Percent of total
<5	4	25.0	<5	2	5.0	<5	13	41.9
<10	9	56.3	<10	10	25.6	<10	21	67.7
<15	11	68.8	<15	17	43.6	<15	26	83.9
≤ 20	14	87.5	≤ 20	23	59.0	≤ 20	28	90.3
<30	15	93.8	<30	26	66.7	<30	29	93.5
>30	1	6.2	>30	13	33.3	>30	2	6.5
	16			39			31	

a Only latter half of May included
b Includes June 1964 and June 1966

TABLE VIII

FREQUENCY OF PREDICTION ERRORS OF THERMOCLINE DEPTH AT STATION PAPA FOR AUGUST, SEPTEMBER, AND OCTOBER*

AUGUST			SEPTEMBER			OCTOBER		
Difference between predicted and observed thermocline depth (ft)	Number of predictions and hindcasts	Percent of total	Difference between predicted and observed thermocline depth (ft)	Number of predictions and hindcasts	Percent of total	Difference between predicted and observed thermocline depth (ft)	Number of predictions and hindcasts	Percent of total
<5	3	9.7	<5	3	11.5	<5	1	5.3
<10	6	20.0	<10	7	26.9	<10	1	5.3
<15	16	53.3	<15	10	38.5	<15	3	15.8
≤ 20	22	73.3	≤ 20	12	46.2	≤ 20	4	21.1
<30	24	80.0	<30	13	50.0	<30	4	21.1
>30	6	20.0	>30	13	50.0	>30	15	78.9
	30			26			19	

* Data represents last half of October mainly

TABLE IX

MEAN VALUES OF PREDICTION ERRORS FOR STATION PAPA

Month	Mean observed thermocline depth (ft)	Mean neg. value of prediction error (ft)	Mean abs. value of prediction error (ft)	Mean pos. value of prediction error (ft)	Mean error from observed (percent)	No. of neg. errors	No. of pos. errors
MAY [a]	89.1	9.8	11.5	16.0	12.9	9	6
JUNE [b]	96.1	32.7	28.8	24.6	30.0	21	17
JULY	92.3	12.8	10.3	8.1	11.2	13	15
AUGUST	103.7	18.1	17.1	10.8	16.5	26	4
SEPTEMBER	90.4	34.5	29.4	12.5	32.5	20	6
OCTOBER [c]	163.1	74.9	74.9	0.0	45.9	19	0

a Includes data from last half of month only
b Includes June 1964 and June 1966 data
c Includes last half of October mainly

TABLE X

CLIMATOLOGY RESULTS VERIFICATION FOR THE GULF OF ALASKA AREA

MONTH	CLIMATOLOGY RESULTS $T_0 - T_{400}$	VERIFICATION $T_0 - T_{400}$
May	3.9	3.83
June	7.1	6.56
July	12.2	10.57
August	15.5	13.14
September	15.1	14.96
October	11.3	10.09

INITIAL DISTRIBUTION LIST

		No. Copies
1.	LT John W. Ciboci, USN TRARON THREE NAAS Whiting Field Milton, Florida	2
2.	Prof. Glenn H. Jung U. S. Naval Postgraduate School Monterey, California 93940	2
3.	Library U. S. Naval Postgraduate School Monterey, California 93940	2
4.	Department of Meteorology & Oceanography U. S. Naval Postgraduate School Monterey, California 93940	1
5.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	20
6.	Office of the U. S. Naval Weather Service U. S. Naval Station (Washington Navy Yard Annex) Washington, D. C. 20390	1
7.	Commanding Officer FWC/JTWC COMNAVMAR FPO San Francisco, Calif. 96630	1
8.	Commanding Officer U. S. Fleet Weather Central FPO Seattle, Washington 98790	1
9.	Commanding Officer U. S. Fleet Weather Central FPO San Francisco, California 96610	1
10.	Officer in Charge Fleet Numerical Weather Facility U. S. Naval Postgraduate School Monterey, California 93940	1

		No. Copies
11.	U. S. Naval Oceanographic Office Attn: R. James Oceanographic Prediction Division Washington, D. C. 20390	1
12.	Executive Officer Department of Oceanography University of Washington Seattle, Washington 98105	1
13.	Director, Biological Laboratory Bureau of Commercial Fisheries U. S. Fish & Wildlife Service 450-B Jordan Hall Stanford, California 94305	1
14.	Mission Bay Research Foundation 7730 Herschel Avenue La Jolla, California Attn: Editor, Oceanic Coordinate Index	1
15.	Director Pacific Oceanographic Group Nanaimo, British Columbia Canada	1
16.	Secretary Canadian Committee on Oceanography Ottawa, Canada	1

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*

U. S. Naval Postgraduate School
Monterey, California

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3. REPORT TITLE

Verification of Mazeika's Method of Thermocline Depth Prediction for the Northeast Pacific Ocean

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(Last name, first name, initial)*

CIBOCI, John William

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
October 1966	66	7

8a. CONTRACT OR GRANT NO. N/A

b. PROJECT NO. N/A

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

N/A

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

N/A

10. AVAILABILITY/LIMITATION NOTICES

[redacted]

11/69

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES

None

12. SPONSORING MILITARY ACTIVITY

Naval Oceanographic Office

13. ABSTRACT

Mazeika's method for forecasting mixed-layer (thermocline) depth of the upper ocean layers is discussed along with a newer version of this method developed by James. Using Mazeika's method primarily, a verification for the Northeast Pacific Ocean was completed with data from Ocean Weather Stations PAPA (50N, 145W) and NOVEMBER (30N, 140W) and a point named MIDPOINT (40N, 140W). The results indicate Mazeika's method is successful at Station PAPA more than seventy-five percent of the time during the heating season followed by a rapid decline as the cooling season begins. The method should be useful in the entire Central Subarctic Domain as described by John P. Tully. The method fails at NOVEMBER and MIDPOINT producing less than thirty percent success in prediction. James' version did not improve the results obtained at Station NOVEMBER. This failure appears to be due to the controlling parameters for processes in the Subtropic or Transitional oceanographic regions (which include NOVEMBER and MIDPOINT); these differ from parameters controlling oceanic processes in the Pacific Subarctic region (Station PAPA), which resemble those involved in the Atlantic region for which Mazeika's method was developed.

Climatology data which can be used to obtain surface and 400-foot level temperature are also tested. The results indicate these data are very useful and accurate in determining the stability index required of Mazeika's method.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Mazeika, Thermocline Depth Prediction						
Verification, James' Version						
Northeast Pacific						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

thesC4788
Verification of Mazeika's method of ther
3 2768 002 10433 3
DUDLEY KNOX LIBRARY